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PROJECTS IN THE HARDWARE RESEARCH GROUP OF THE DEPARTMENT OF COMPUTER SCIENCE OF THE UNIVERSITY OF ILLINOIS

by

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APRIL, 1968

DEPARTMENT OF COMPUTER SCIENCE
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN · URBANA, ILLINOIS

PROJECTS IN THE HARDWARE RESEARCH GROUP

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1. GOALS OF THE HARDWARE RESEARCH GROUP

The overall goal of the Hardware Research Group is the exploration of new and uncommon forms of information encoding and processing. Four main areas are under investigation:

1. Hybrid digital-analog circuits and systems
2. Stochastic computing circuits and systems
3. Electro-optical devices and systems
4. Display devices and systems

2. HISTORY OF THE GROUP

The present Hardware Research Group started about 10 years ago as the Circuitry Research Group in charge of the implementation of Illiac II. It was responsible for the following technical innovations:

1) Current steering flip-flops and logic
2) Variable topology circuits
3) Flow gating
4) Selector gating
5) High sensitivity flip-flop with built-in gates
6) Speed independent computing circuits

More recently the group was responsible for high speed circuit research and championed the following ideas:

1) Virtual load two-wire information transfer
2) Auto-pump tunnel diode circuits
3) Active transmission lines

Three years ago, thanks to AEC financing, larger scale operations were made possible and led to contributions in the area of:

1) Multi-megacycle hybrid circuits
2) Stochastic computing circuits
3) Electro-optical processing
4) Static "intelligent" displays

Presently the group is engaged in a multitude of projects, described in the list below (the status of each project is indicated by a precentage after the title).

3. HYBRID CIRCUIT RESEARCH

3.1 PHASTOR (100)

The PHASTOR is a phase-locked multivibrator synchronized on harmonic 100 of a centralized clock. A three transistor circuit can store 100 different phase differences with respect to the fundamental clock, and the storage of quantized analog variables can be obtained by a voltage-to-phase-difference converter. The general principle of a storage cell is shown in Figure 1. Stability of a four cell model has proved outstanding and voltages between -10 and +10 volts have been stored to within 1% over periods of several days.

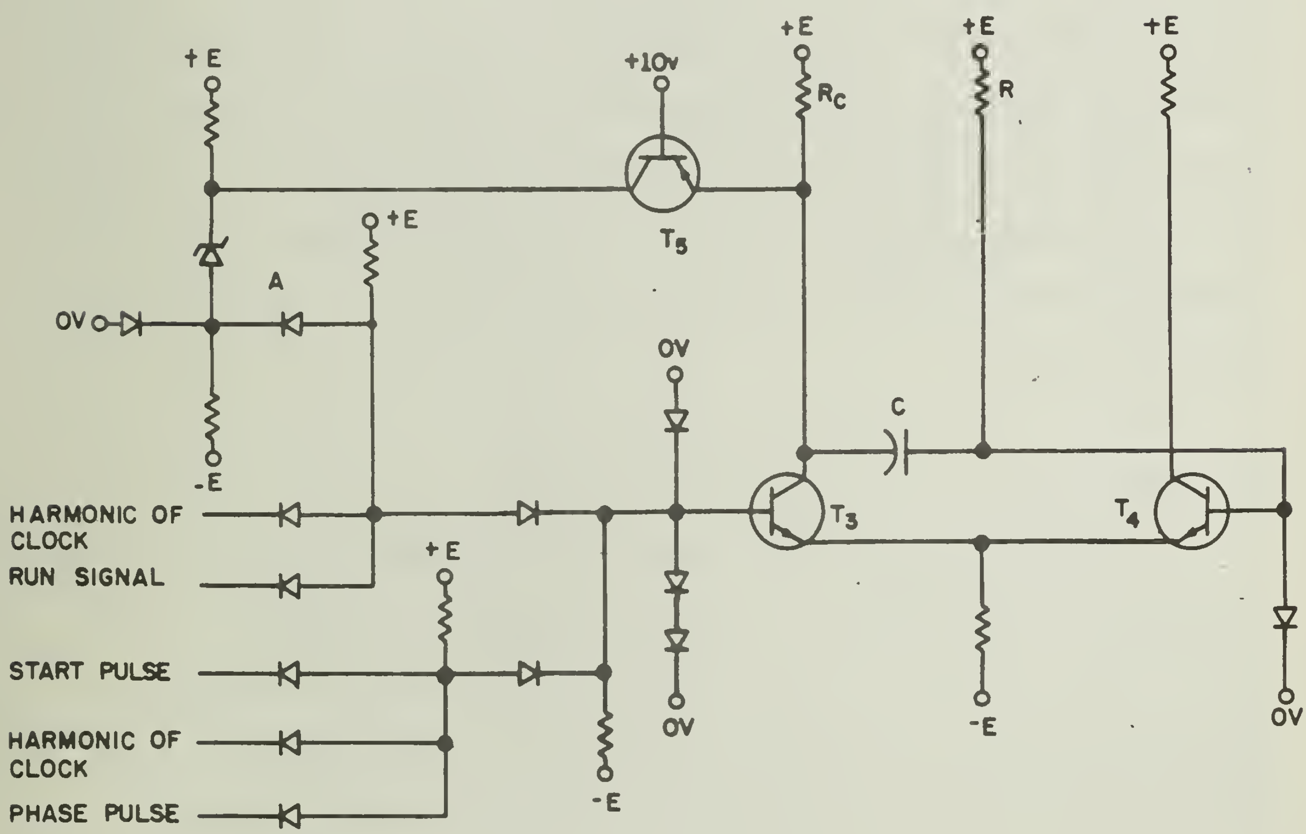


Figure 1. PHASTOR Cell

3.2 PARAMATRIX (100)

The fundamental PARAMATRIX system shown in Figure 2 allows the digitization of an incoming line drawing or bubble chamber photograph into a 32 x 32 array of binary signals, in such a way that the digitization is preceded by electronic translation, rotation and magnification of the image. The system scans the output matrix and for each point x_i, y_j forms

$$X_{ij} = (x_i \cos + y_j \sin)m+a$$

$$Y_{ij} = (-x_i \sin + y_j \cos)n+b$$

A very fast flying spot scanner decides in about one microsecond whether (X_{ij}, Y_{ij}) is on the input slide: If yes, matrix point x_i, y_j is made 1, otherwise it is left at the zero level. The circuits in PARAMATRIX combine analog and digital signals in the most intimate manner, meaning that all information signals are analog, while all steering signals are digital. All circuits are capable of 2 megacycle operation with .3% accuracy and allow a swing from -10 volts to +10 volts.

3.3 ARTRIX (100)

The ARTRIX system, shown symbolically in Figure 3, has essentially the same properties as the MIT SKETCHPAD system, but differs from it by the fact that no back-up digital computer and core memory are necessary. The graphical information is stored in four memotron-vidicon pairs and on-line video processing gives the desired

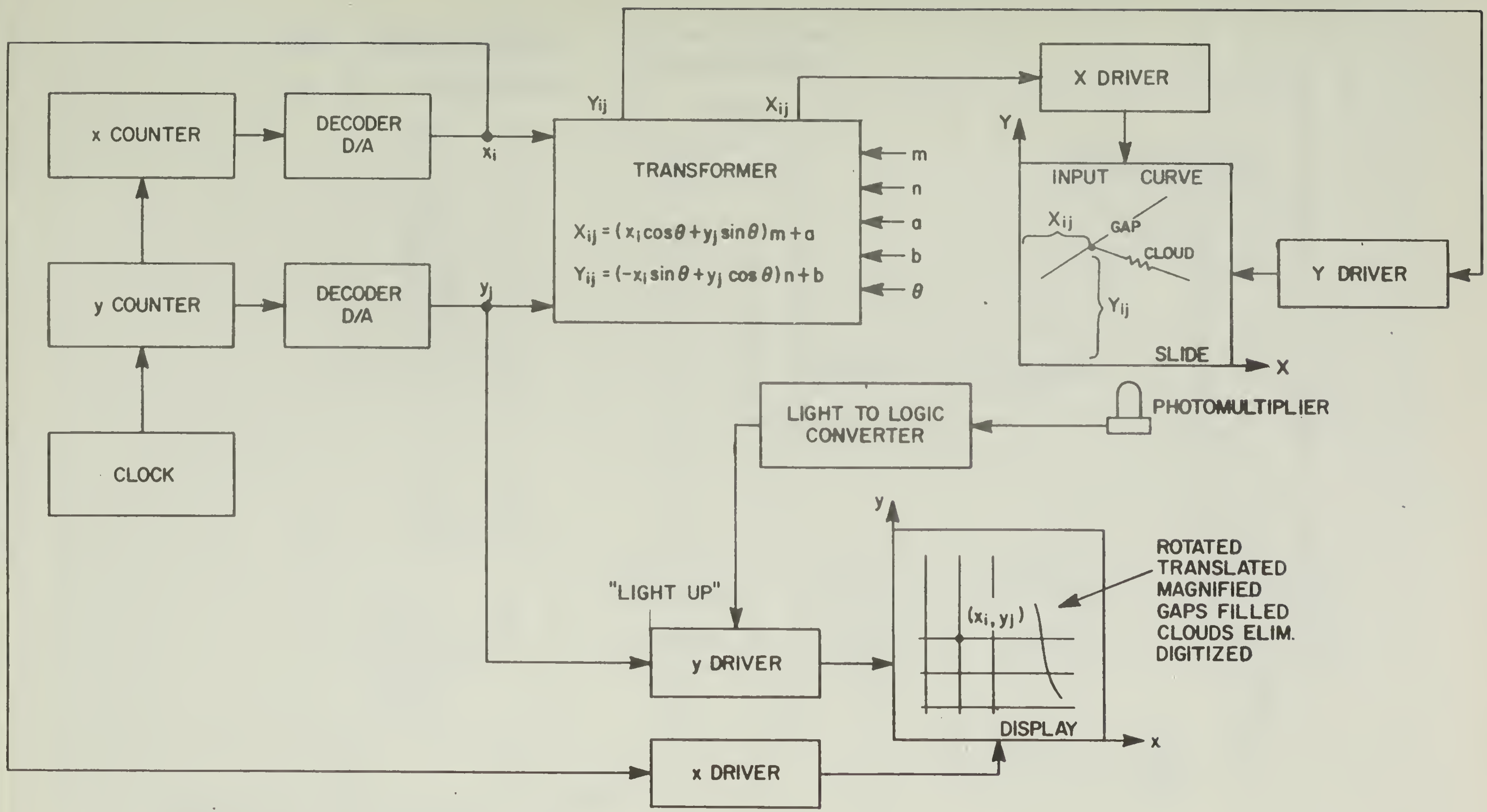


Figure 2. PARAMATRIX Block Diagram

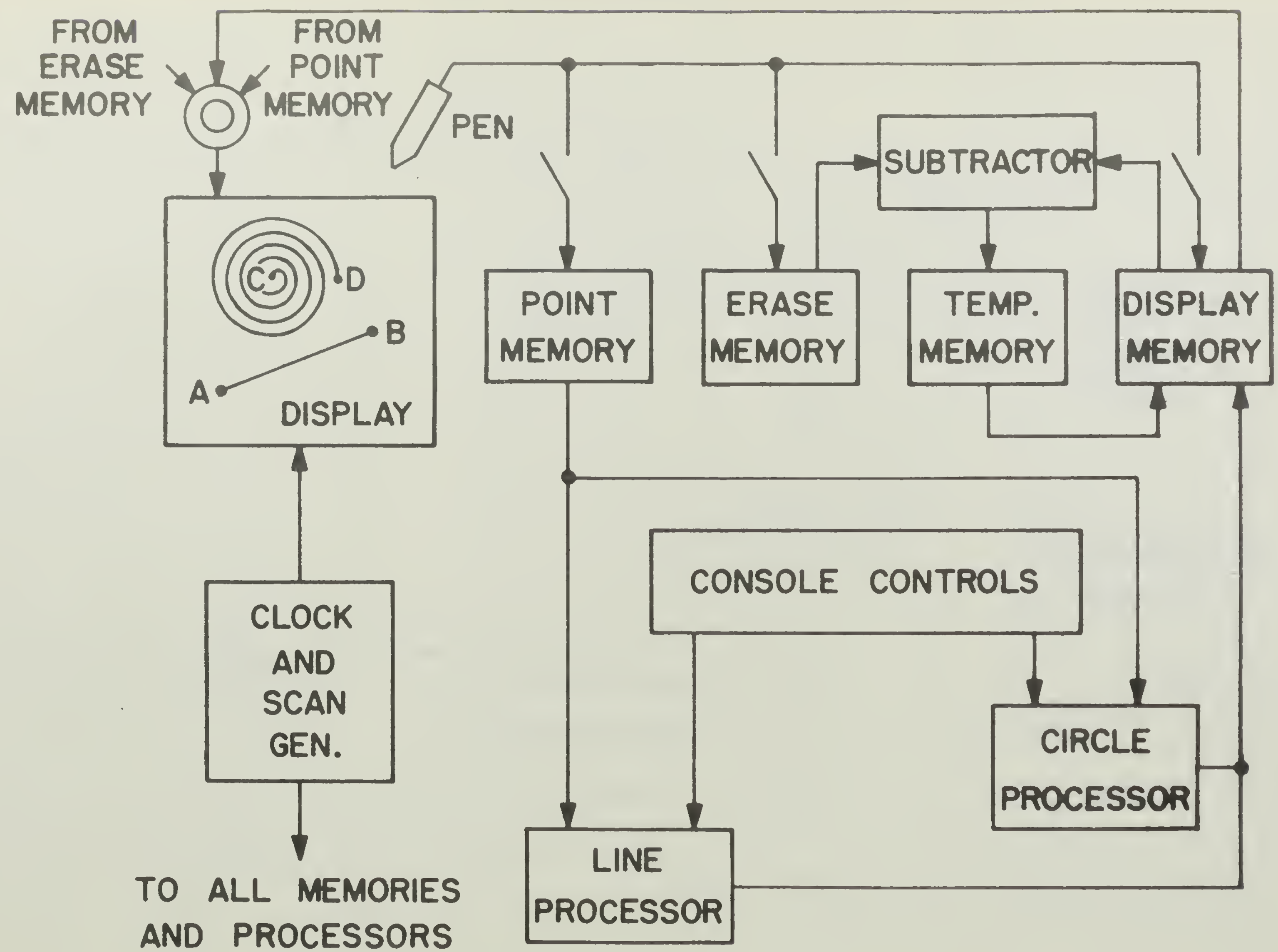


Figure 3. ARTRIX Block Diagram

geometrical constructions on the display monitor. Drawing a circle with a given center and a given radius is accomplished by generating an expanding spiral which, upon touching a point on the circumference, is "frozen" and displayed for its last turn. ARTRIX allows construction of straight lines and circles, parallel translation, labelling and erasure.

3.4 TRICOLOR CARTOGRAPH (90)

The TRICOLOR CARTOGRAPH is an on-line hybrid machine with a tri-color display tube and a video storage disc. On-line hybrid processing allows the operator to indicate the inside of a region delineated by a boundary and to color it red, green, or blue at his choice by pushing an appropriate button. The overall principle is shown in Figure 4: The light pen generates a vertical through the indicated point and the hybrid computer colors every scan line intersecting this vertical between the boundary that is to the left and the boundary that is to the right of it. If portions of the area are not colored in this way, a slight movement of the pen will correct the situation.

3.5 INFORMATION REDISTRIBUTION BANDWIDTH COMPRESSION SYSTEM (60)

In this system the times taken for a scanning beam to move from the lefthand edge to successive intersections of the lines of a drawing are measured electronically and stored as numbers in a sequence of 32 registers (see Figure 5). While the next line is being scanned and the results stored in a second group of 32 registers, the numerical contents of the first set of registers are read out at steady 2 microsecond intervals. The receiver stores the contents of the registers, and the beam of the display CRT is lit up at the time indicated by receiving register. It is easy to see that in this fashion the worst case for bandwidths, i.e. all 32 lines for instance in the upper lefthand corner, is eliminated by taking a whole line scanning interval

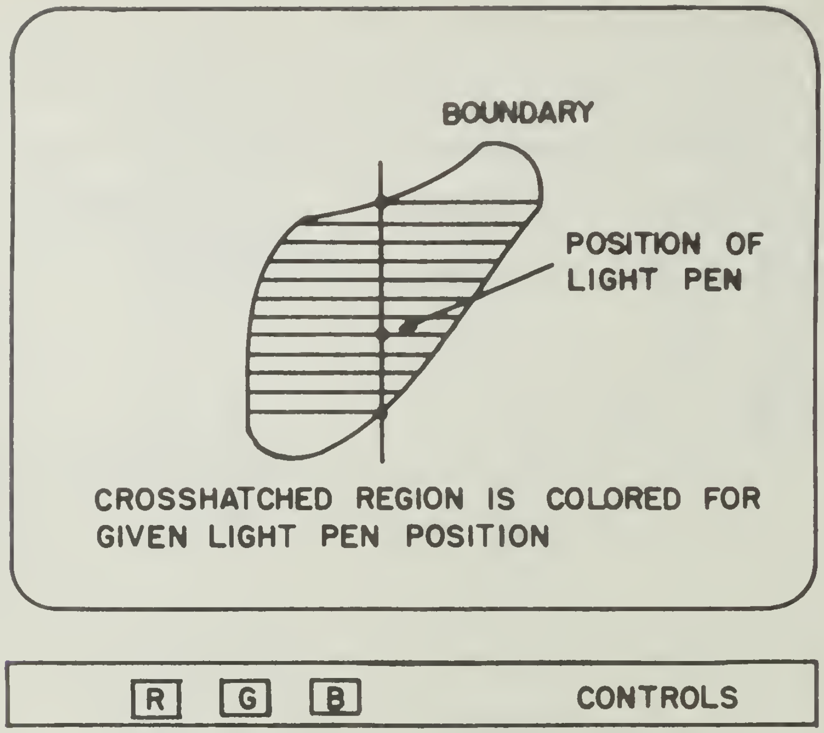


Figure 4. Operation of Tricolor Cartograph

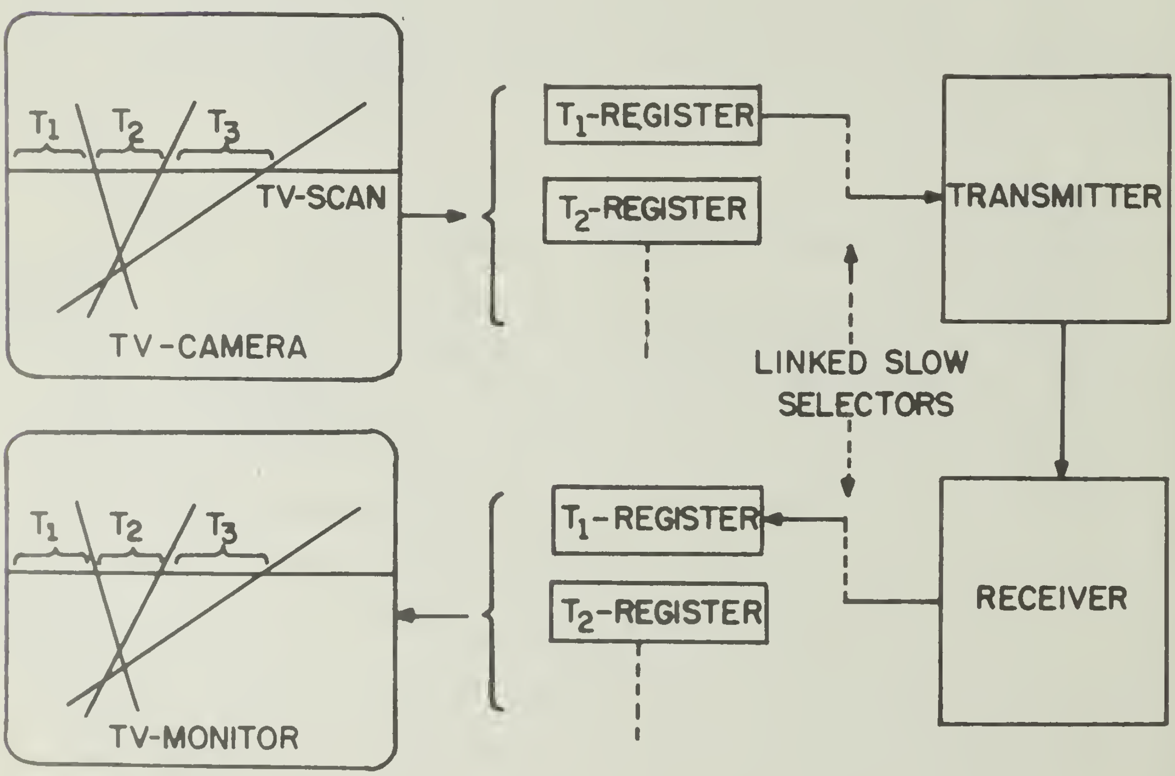


Figure 5. Principle of the IRBC System

of 64 microseconds to transmit the necessary information. It is possible to complement the system by an automatic bandwidth adaptor such that 16 kilocycles of bandwith are necessary for each line in the drawing.

3.6 VISTA SYSTEM (VARIABLY INTERLACED SCAN TELEVISION APPARATUS) (20)

The VISTA System, shown symbolically in Figure 6, explores the possiblity of synchronized pseudo random scanning in which the number of lines per frame is made a function of the variation in information content

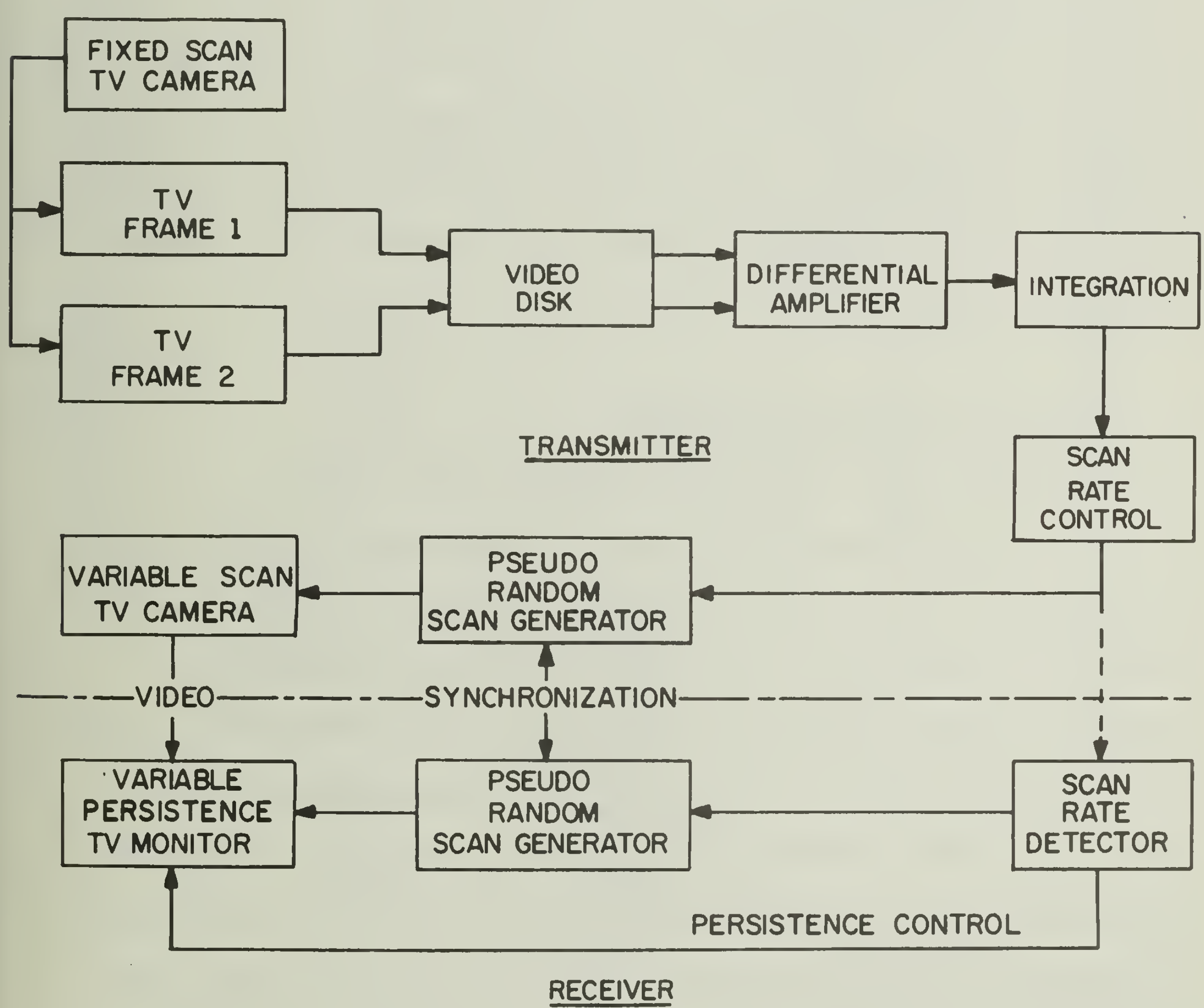


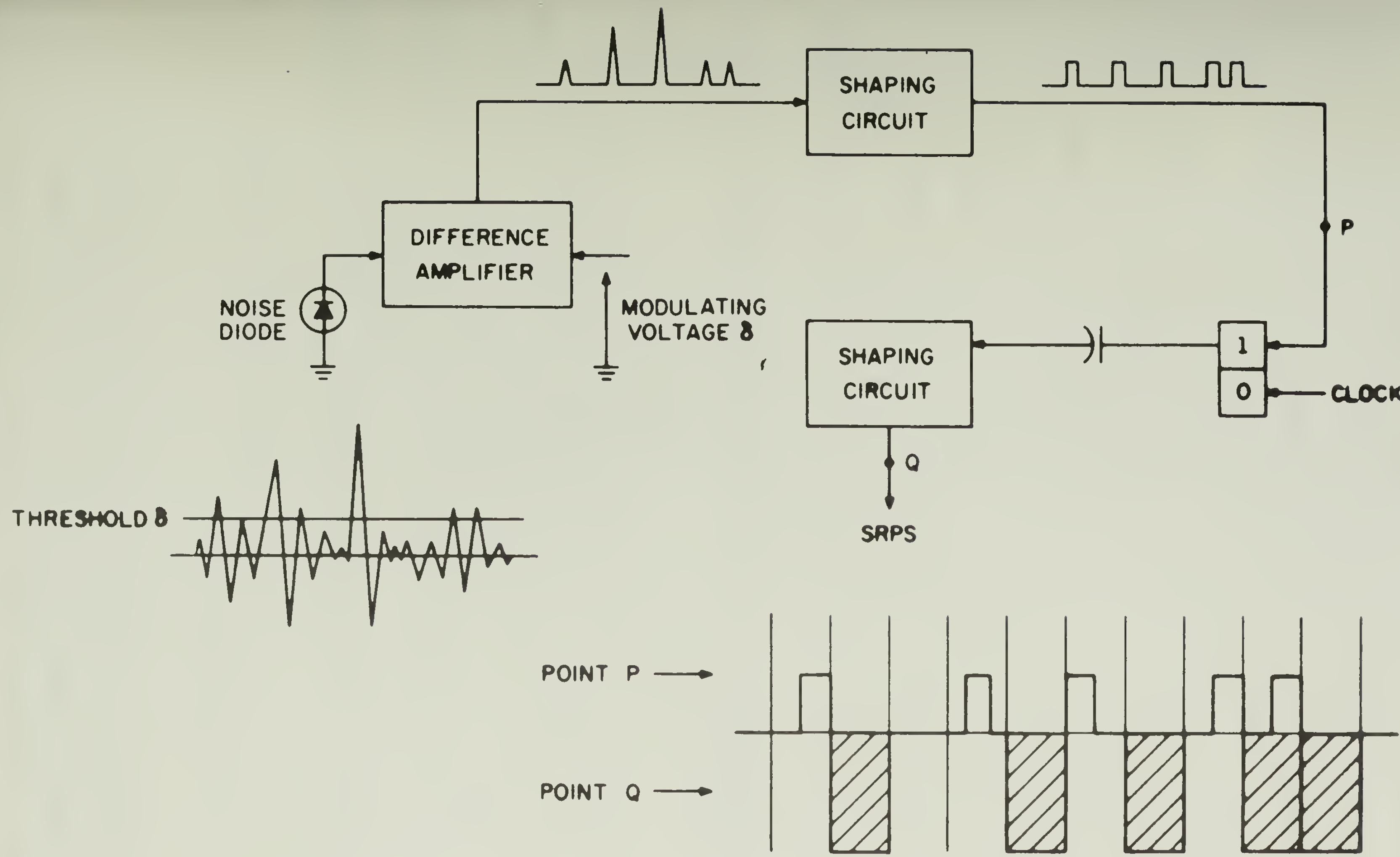
Figure 6. Block Diagram of the Vista System

in adjacent frames. To this effect a video disc stores the successive frames, and the integrated output of a difference amplifier (connected between two tracks) controls the number of lines in digital steps, i.e. 512, 256, 128, 64, 32 and 16. In order to compensate for small line numbers, the receiver contains a variable persistence display, in which the integration constant is made inversely proportional to the number of lines. In extreme cases, i.e. when nearly static displays are to be transmitted, the system will integrate over 32 frames and use a one second build-up time for its output. If all information changes between two frames, the integration time will be reduced to 1/30 second and a 512 line frame is transmitted. The principal goal of the project is to explore the elimination of picture roll by the pseudo random scanning system, as well as the use of variable scan rate vidicons and variable persistence output devices.

4. STOCHASTIC INFORMATION PROCESSING

4.1 FUNDAMENTAL IDEA OF STOCHASTIC REPRESENTATION (100)

The goal of stochastic variable representation inside computers is to simplify to the utmost the hardware necessary for the fundamental operations of arithmetic. To this end an arrangement according to Figure 7 is used to convert an analog voltage into a random pulse sequence such that pulses can only occur in given time slots, and that the probability of the occurrence represents the (normalized) variable value. It is evident that multiplication of two variables can be simply obtained by running the corresponding pulse sequences into an AND circuit: The probability of an output pulse is equal to the product of the input



PRODUCTION OF SYNCHRONOUS RANDOM PULSE SEQUENCES

Figure 7. Analog to Stochastic Conversion.

probabilities. Two types of processing have been investigated: One in which the operations of arithmetic are done by feedback steering of appropriate random pulse generators, and the other using purely digital processing. The latter type is now favored because of the potentially much higher precision that can be obtained. The precision is of the order of 10% for an average sample of 100 pulses, 1% for a sample of 10,000 pulses and .1% for 1,000,000 pulses. Buffering has to be used to store pulses in case of coicidences in addition, non-presence of a pulse in the subtrahend in subtraction, etc. It is interesting to note that the rules corresponding to the four fundamental operations of arithmetic shown in Figure 8, and realized in the general computation element, are:

1. Multiplication: Put out a pulse when pulses come in simultaneously.

2. Addition: Put put a pulse if a pulse comes in one one line or the other (by an OR circuit) and store a pulse occurring on coicidence until a free slot is found in the output sequence.

3. Subtraction: Subtract the subtrahend pulse from the minuend pulse if present, otherwise on the next occasion when a minuend pulse occurs.

4. Division: For each dividend pulse, start an output sequence of pulses upon occurence of the next divisor pulse which lasts until one more divisor pulse occurs.

More recently a system of representation was investigated in which numbers are represented as quotients, the numerator and denominator being represented by random pulse sequences. It can be proved that in this representation no buffer storage is necessary and that all operations of arithmetic can be done with combinatorial logic only.

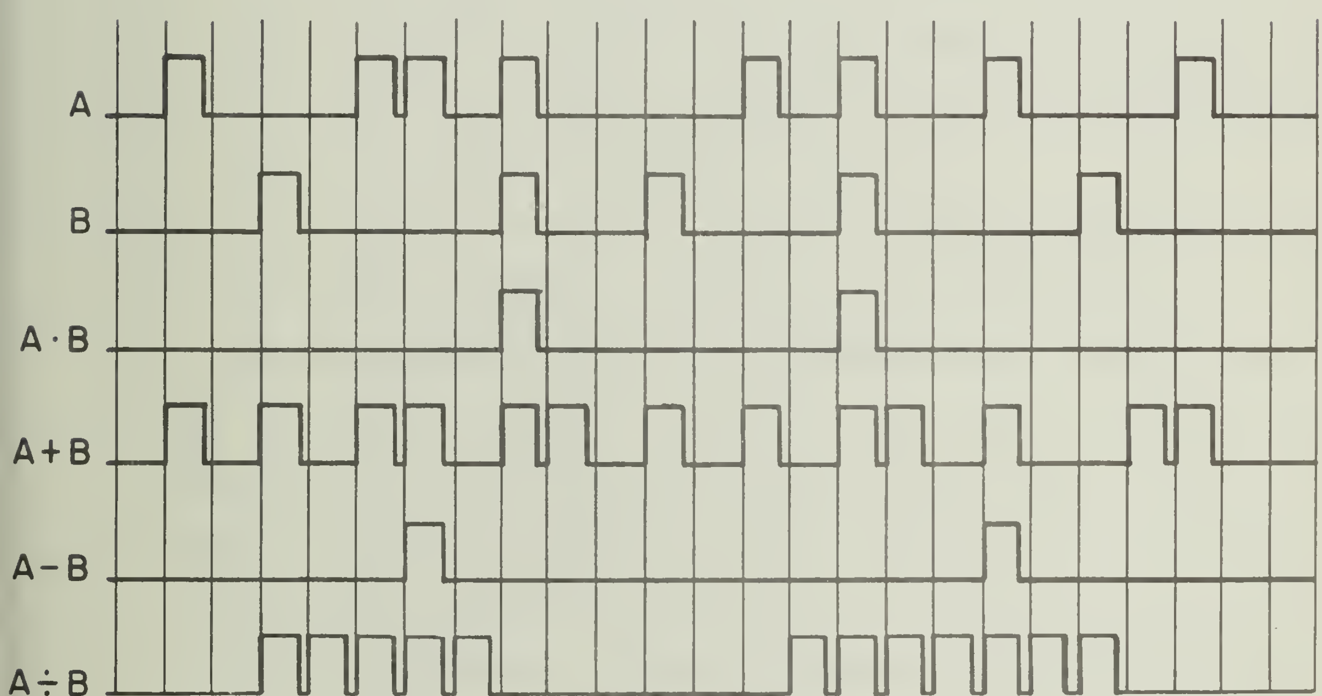


Figure 8. The Four Fundamental Operations using Stochastic Sequences

4.2 FIXED TOPOLOGY ARRAY COMPUTER (50)

In this computer (shown in Figure 9) a general computation element using stochastic representation is used with a fixed interconnection pattern. Each cycle of the program corresponds to the impression, upon the array, of the type of operation desired of each element. Such an array computer is a prime target for integrated circuitry, since each general computation element only necessitates two input and one output wire as well as two digital control leads to define the operation. A model with about 26 junctions is presently being discussed with T. I. The Figure 9 shows a possible array capable of forming continuous fractions. A simple algorithm allows the definition of all operations by simple inspection of the continuous fraction written in polish notation.

4.3 TRANSFORMATRIX (20)

TRANSFORMATRIX is an application of stochastic processing in which the light values furnished by a 32 x 32 photodiode matrix are transformed into 1024 stochastic sequences. These sequences are multiplied one by one by 1024 weights, defined by a weight matrix or more exactly by their stochastic sequences. The result of the multiplication and addition of all terms is displayed on a 32 x 32 output matrix, the coefficient matrix being a function of the output point. The 1024 x 1024 coefficients necessary to do this operation define all possible (quantized) translations, rotations, magnifications, convolutions, conformal mappings and even Fourier Transforms. The principle of the system is shown in Figure 10. In the model presently being designed, the coefficients corresponding to each output point are calculated by a small special purpose computer, illustrating the fact that memory space and computational ability are often interchangeable.

$$F = r/(s+t) + gh/(tw + b/(dp+y))$$

$$F = t(B)(B)s(B) + r(B)\backslash(B)y(B)(B)p(B)dx + b(B)\backslash t(B)wx + h(B)gx\backslash +$$

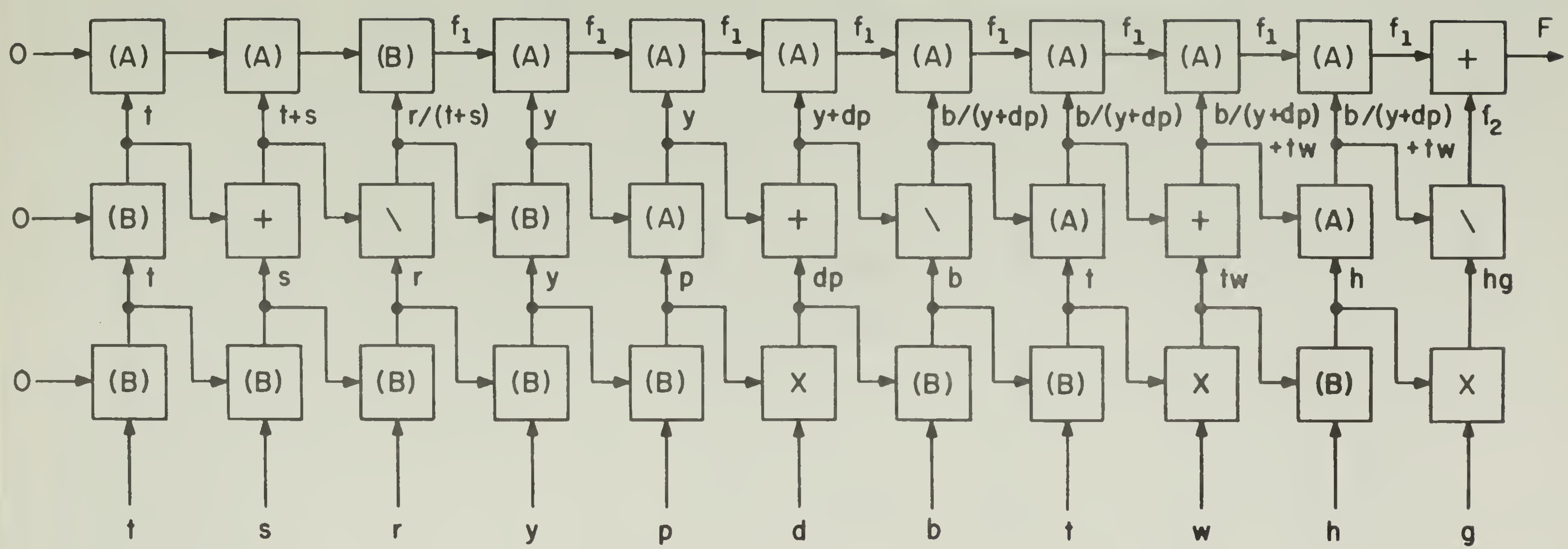
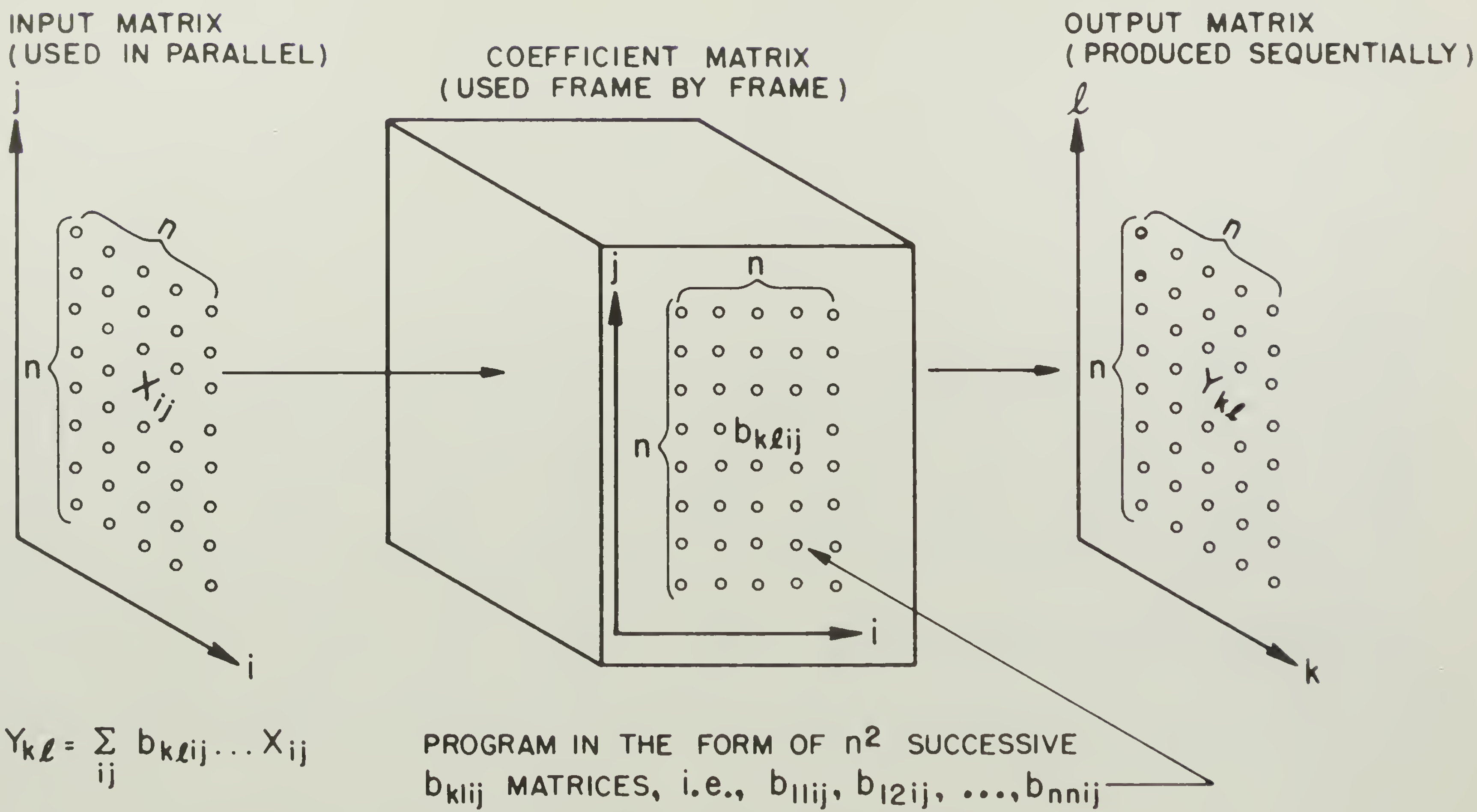


Figure 9. Stochastic Array Computer



TRANSFORMATRIX

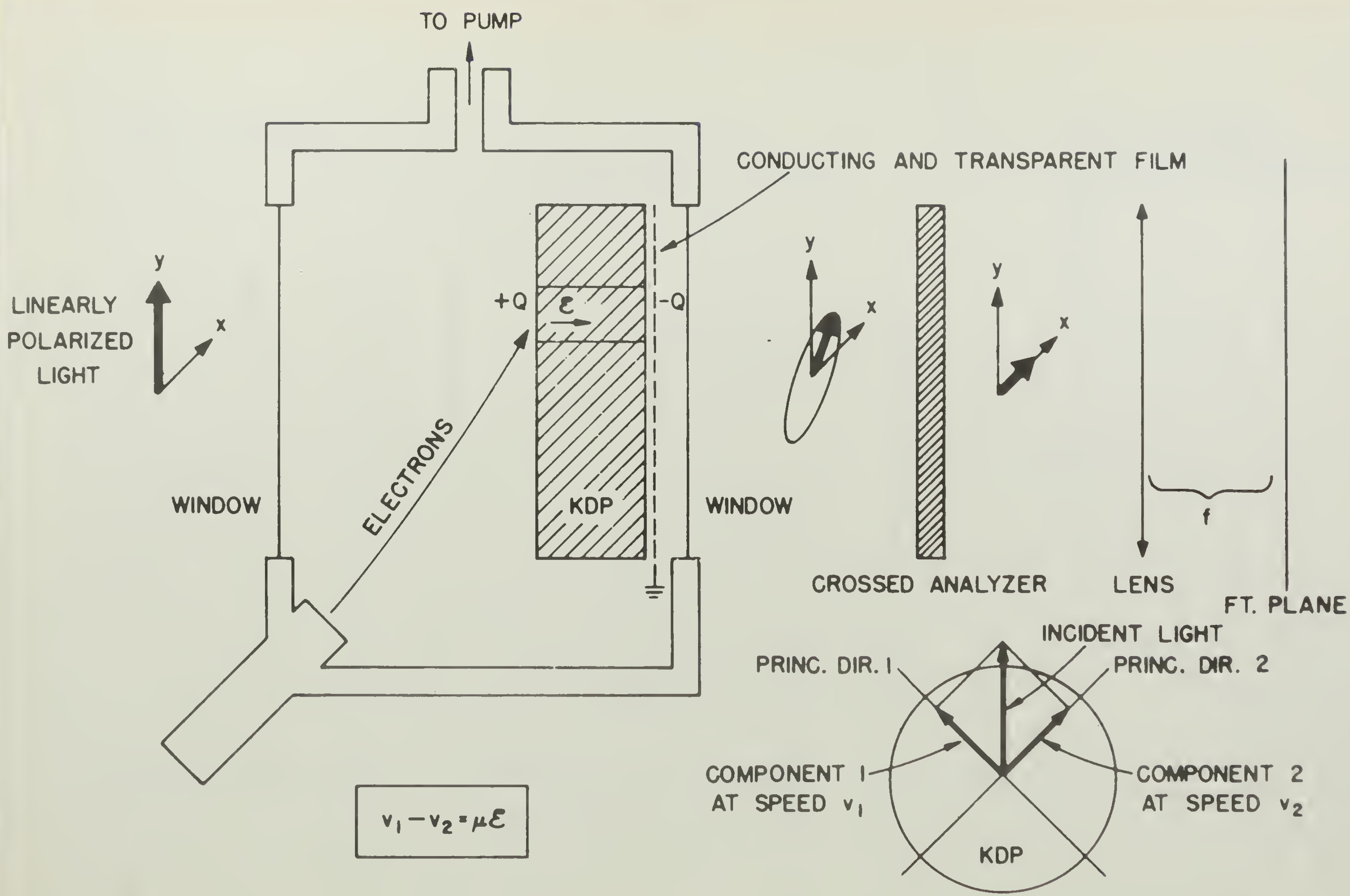
5. ELECTRO-OPTICAL WORK

5.1 ON-LINE FOURIER TRANSFORM (80)

The On-Line Fourier Transform System is shown in Figure 11 and consists essentially of an Ardenne tube, illuminated by a continuous laser, and an optical system forming a spatial Fourier Transform in the focal plane of a lens. The Ardenne tube contains a KDP cyrstal which is scanned by an electron beam, so that the charge distribution represents a video picture. This charge distribution is translated into a modification of the state of polarization of the laser light, which can be detected by an analyzer between the lens and the Ardenne tube: Essentially we have an instant transparency, produced electronically.

5.2 NOISE ELIMINATION PROJECT (50)

As shown in Figure 12, periodic noise superimposed on a video signal corresponds to a striation of the picture. This striation varies from one frame to the next by translation only and the Fourier Transform of the striation remains constant. Periodic noise in interplanetary television can therefore be eliminated by sending a sequence of frames of the form "noise only", "video plus noise," etc. It is then possible to subtract the Fourier Transform of the noise from the Fourier Transform of the composite signal for noise elimination purposes: The inverse transform of the difference contains much less noise.



ARDENNE TUBE (ROME ARDC–ILLINOIS VERSION)

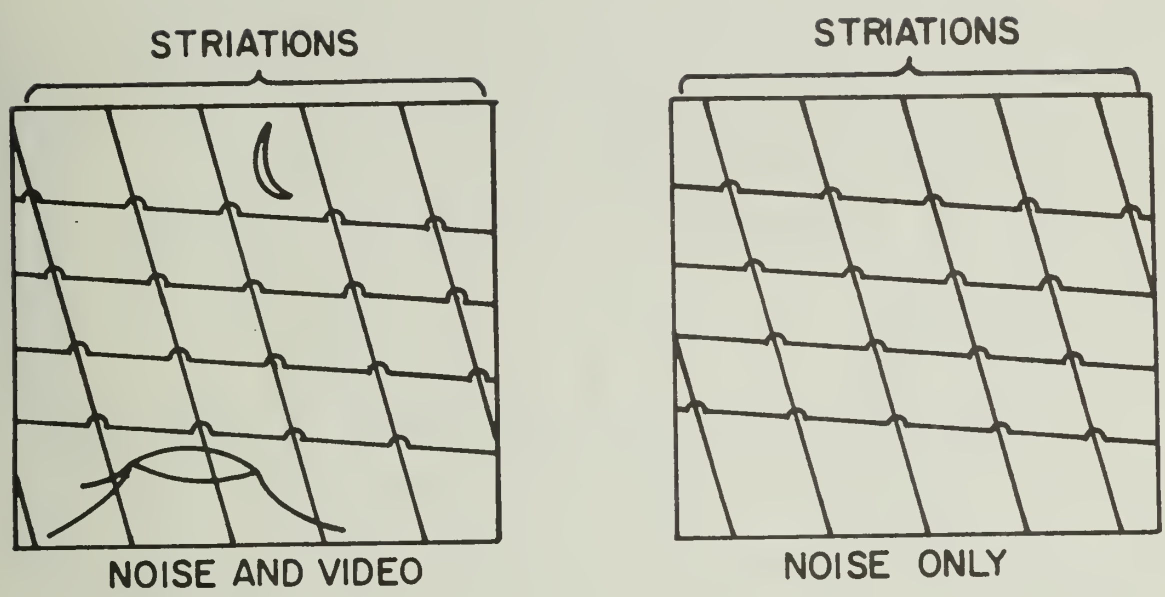


Figure 12. Periodic Noise in Adjacent Video Frames

5.3 ON-LINE HOLOGRAPHY FOR 3D DISPLAYS (10)

Using the Ardenne tube described above, it is possible to produce a 3D image by writing appropriate charge distributions onto the KDP crystal. This project is further described below.

5.4 PHOTOCONDUCTIVE CROSSBAR SWITCH (100)

Here a 4 x 4 matrix of T-connected photoconductive cells is scanned by a laser. The bar of the T is connected between the wires crossing at each node of a 4 x 4 array, with the stem connected to ground. The scanning of the laser is performed by two 20 kilocycle mirror galvanometers and is such that the stem of all cells is illuminated, except when the two wires in a node should be connected: then an additional "twitch" directs the light onto the cells connecting the wires. The cells have very short rise times and very long decay times and hi-fi quality transmission can be obtained, even if the laser beam moves away for considerable periods of time to fulfil its functions elsewhere. Figure 13 shows the general layout.

6. DISPLAY DEVICES

6.1 GEOMATRIX (100)

GEOMATRIX, shown in Figure 14, has an array of crossing wires attached to voltage dividing networks at the edge, and uses a zero voltage detection element at each intersection. When two arbitrary points of the array are forced into the same potential state (indicated symbolically by the sliding switches on the voltage dividers), it is easy to see that all points on a straight line joining the indicated points will also be at the same potential and will therefore light up.

6.2 POTENTIOMATRIX (50)

POTENTIOMATRIX is a more sophisticated version of GEOMATRIX in which we impose fixed potentials upon certain "islands" of nodes, all nodes being connected by a matrix of resistors. Each node is also connected to a bus via a zero voltage indicator and it is evident that, as the bus has its voltage stepped from the potential of the first island to that of the second, equipotential lines will be displayed. POTENTIOMATRIX is the first attempt to design an "intelligent display", meaning a display capable of a certain amount of graphical processing in the display device itself. The ultimate goal in developing such display devices is bandwidth reduction when communicating with a computer. It is, for instance, easy to see that the drawing of conical sections corresponds to the indication of the directrix, the focal point and a potential ratio. Figure 15 shows the principle of POTENTIOMATRIX.

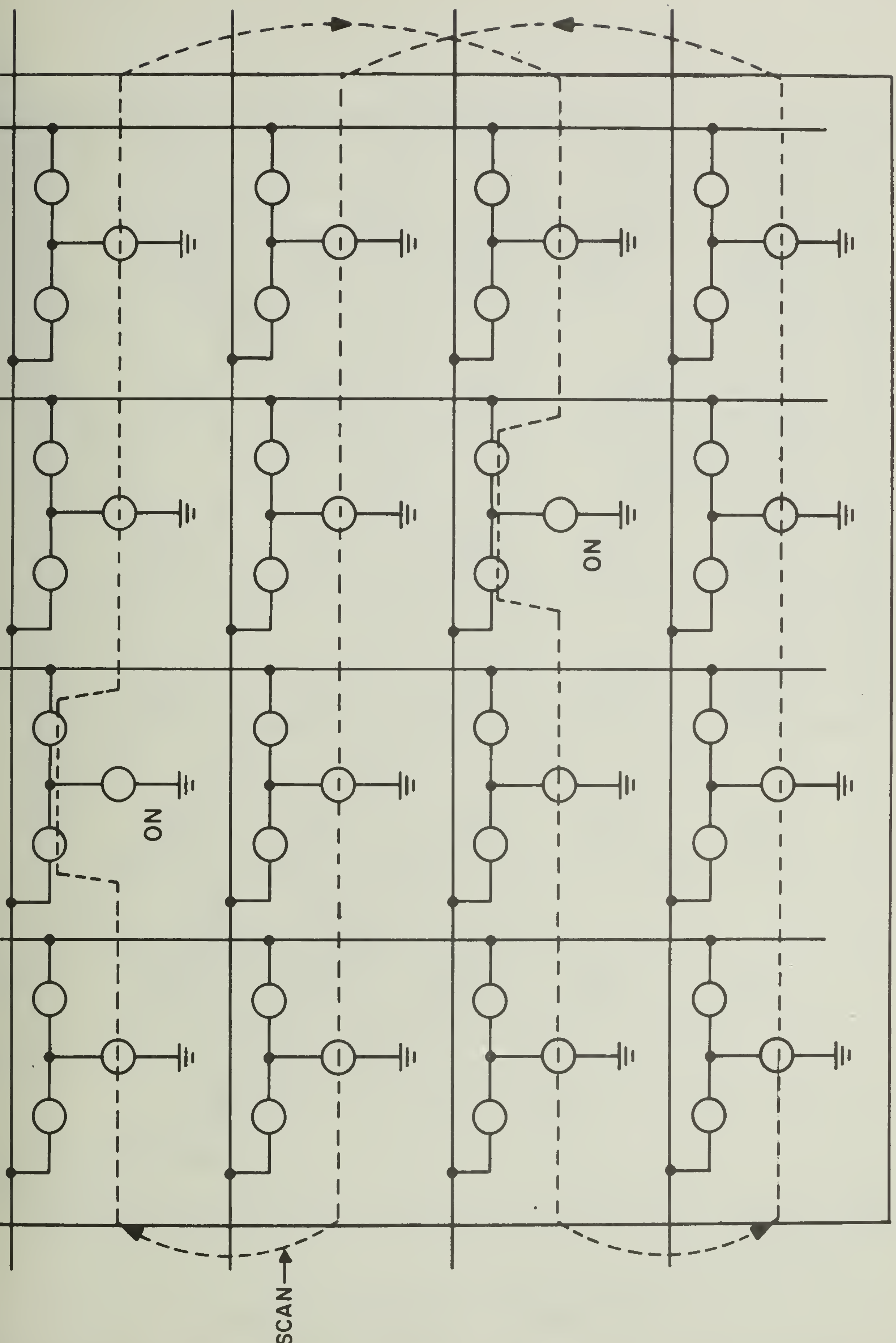


Figure 13. Photoconductive Crossbar Switch

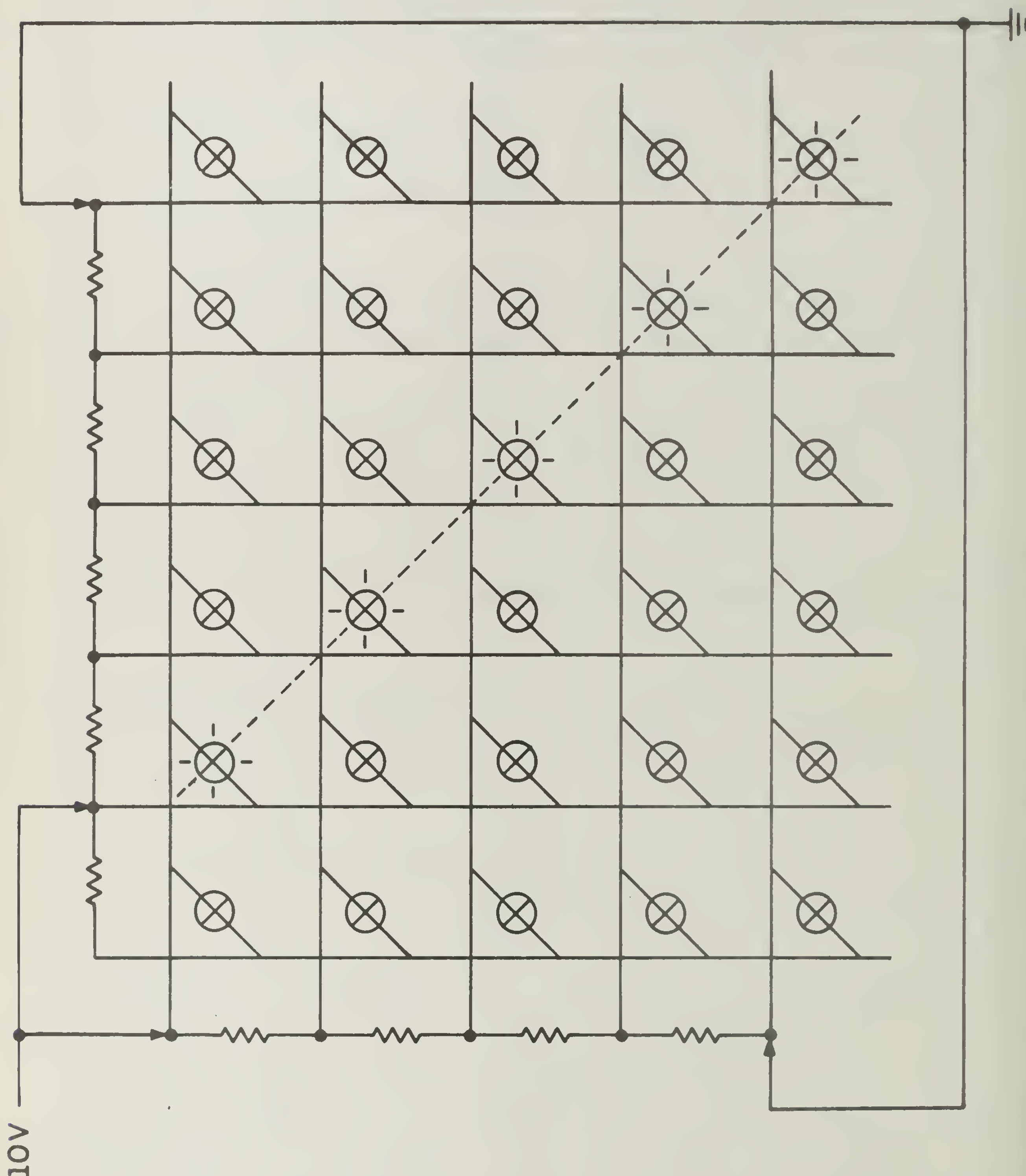
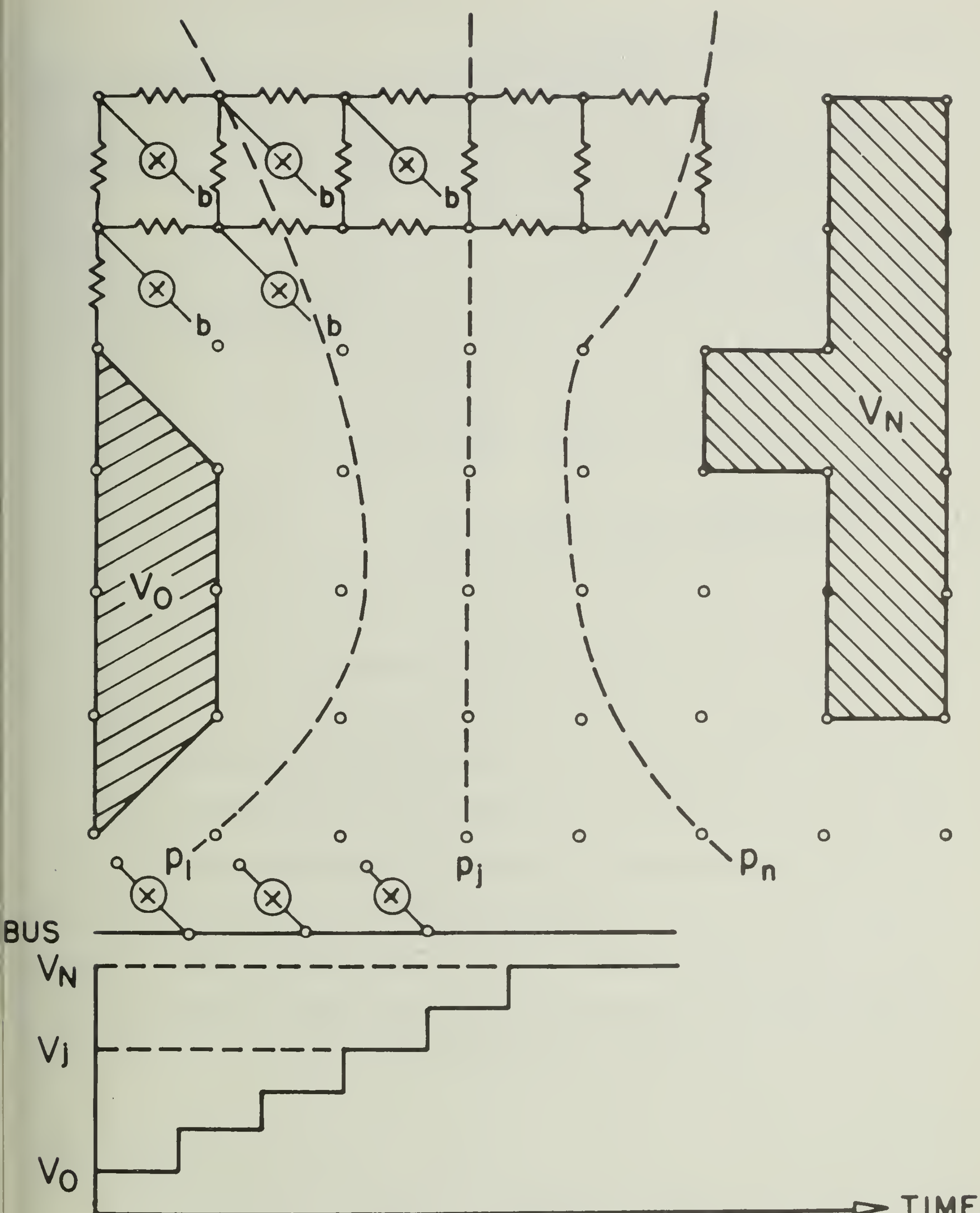


Figure 14. GEOMATRIX



INTELLIGENT DISPLAY

Figure 15. Principle of POTENTIOMATRIX

6.3 ELECTROLUMINESCENT PANEL (100)

Due to the non-linearity of operation and the high voltages required, the access of electroluminescent panels of n^2 points with only 2x wires has always posed a problem. The 28 x 28 matrix in the computer laboratory is driven from a fixed memory in the form of toggle switches by a coincident voltage system using 400 volt pulses. The circuits scanning the fixed memory transform the information into timing parameters and use the latter to steer the voltages on the 2n wires. Reasonably good uniformity and brightness have been obtained.

6.4 LARGE SCREEN TELEVISION (10)

One of the fundamental reasons why the simple mirror deflection system for intense light sources had to be rejected, is the inability of mirrors of high inertia to follow phase jumps in the synchronization. In this system (see Figure 16) a scan converter is used as an interface memory into which the television receiver writes (as if the converter were a kinescope) and out of which the mirror-modulator system reads at its own speed, synchronized by the rotating mirrors. A strong light source (arc or laser) is modulated by a KDP or an ultrasonic modulator. Chromatic aberration is a problem: The extension to color is attractive because of the possibility of using three single color modulators.

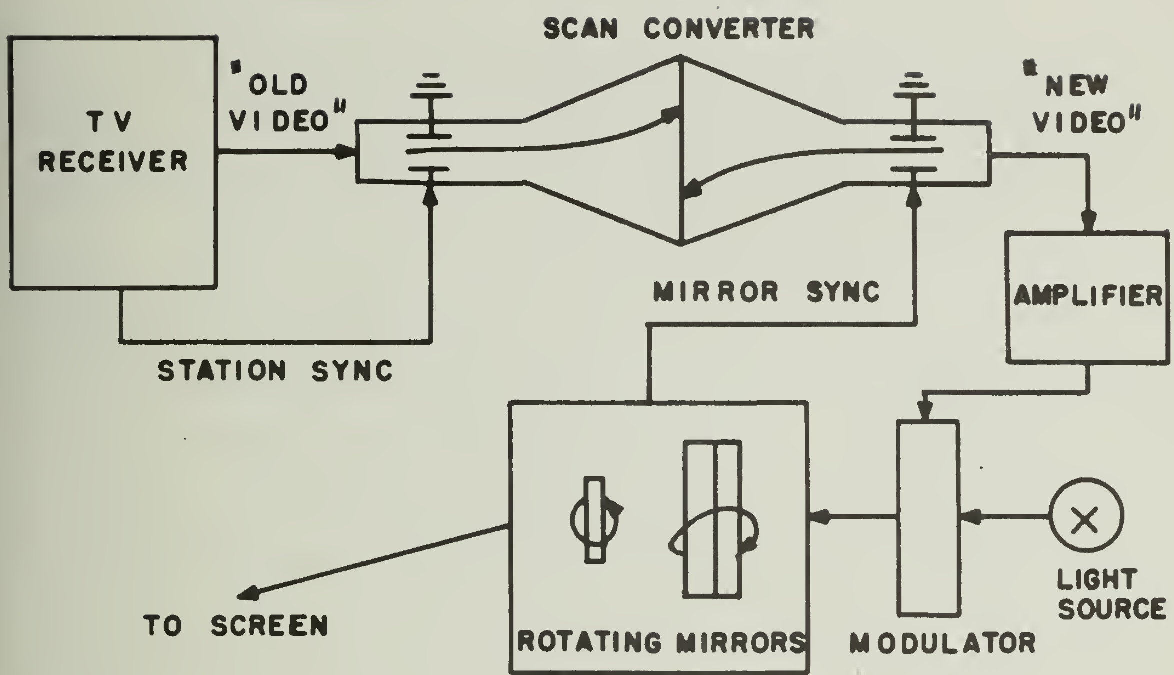


Figure 16. Large Screen TV

6.5 HOLOGRAPHIC 3D DISPLAY (30)

This display, as already mentioned above, uses an Ardenne tube, or better a KDP crystal as the carrier of the hologram. Unfortunately even the "short Fourier Transform" and other tricks do not allow the on-line calculation of the hologram of simple geometrical figures in space. This project investigates the possibilities of forming such hologram by purely electro-optical methods.

6.6 XOGRAPHIC VIDEO DISPLAY (10)

As indicated in Figure 17, this display method uses the cylindrical lens method having lately become popular under the name

"Xography": The cylindrical lenses are in a plane perpendicular to the line of vision and throw the "left eye" and "right eye" information into the corresponding eye by imaging pairs of strips under each cylindrical lens. In the video adaptation of the method, the scanning direction on the output tube is made vertical and the odd and even field signals correspond to the input from two appropriately placed video cameras forming a stereo pair. The alignment problem, i.e. the problem of having a pair of interlaced lines under the cylindrical lenses embossed on a television tube, is solved by appropriate electronics and should not be harder than the alignment problems in a tricolor tube.

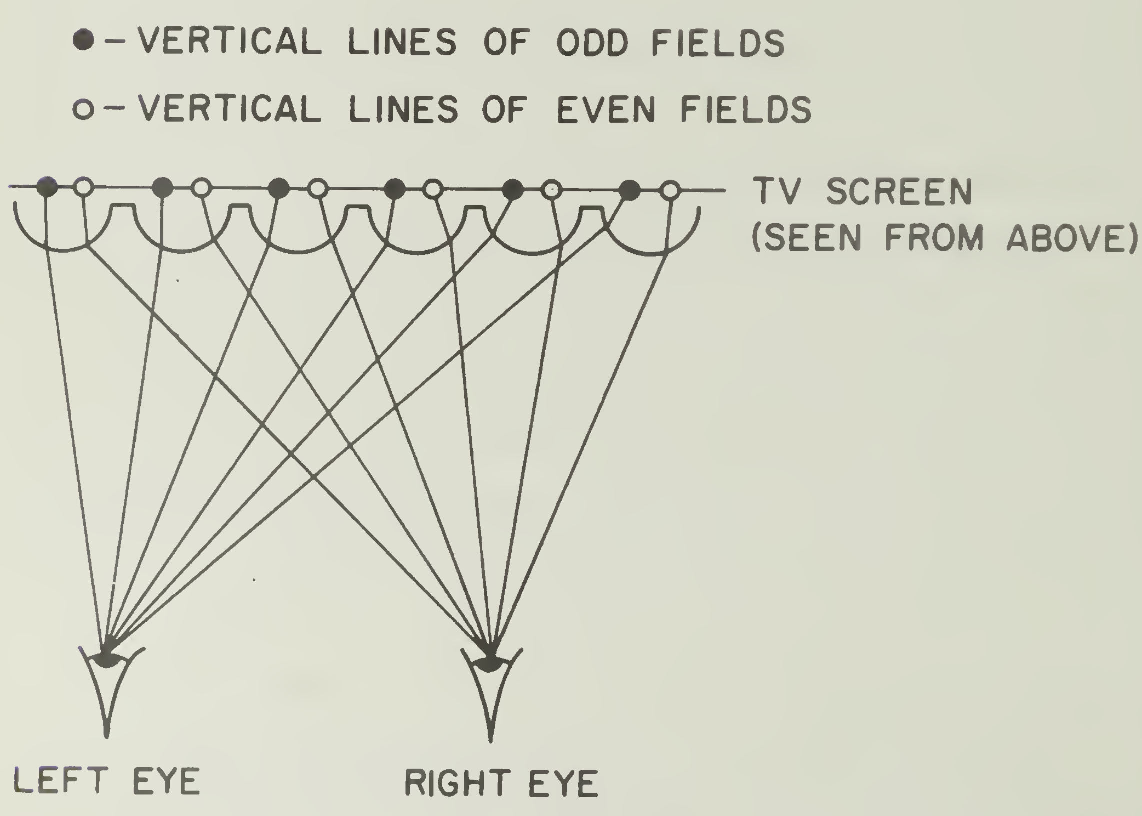


Figure 17. TV - Xography

6.7 STEREOMATRIX (10)

The principle of STEREOMATRIX is shown in Figure 18. Here use is made of the knowledge gained in the PARAMATRIX problem, i.e. our ability to form on-line coordinate transformations. The display has to be furnished with a list of triplets of points (x, y, z) and an appropriate high speed analog computer forms (X', Y') as well as (X'', Y'') where these new coordinates correspond to the projection of (x, y, z) onto a display screen of axes X and Y, as seen by the left eye and the right eye respectively. The natural polarization of laser light is used to distinguish the "left projection" and the "right projection" and the projections are viewed through appropriate polarizing glasses. Note that a detector for the position of the observer can be used to modify the transformation as a function of his position with respect to the display. Also note that a Z-transform can be used to modulate the intensity.

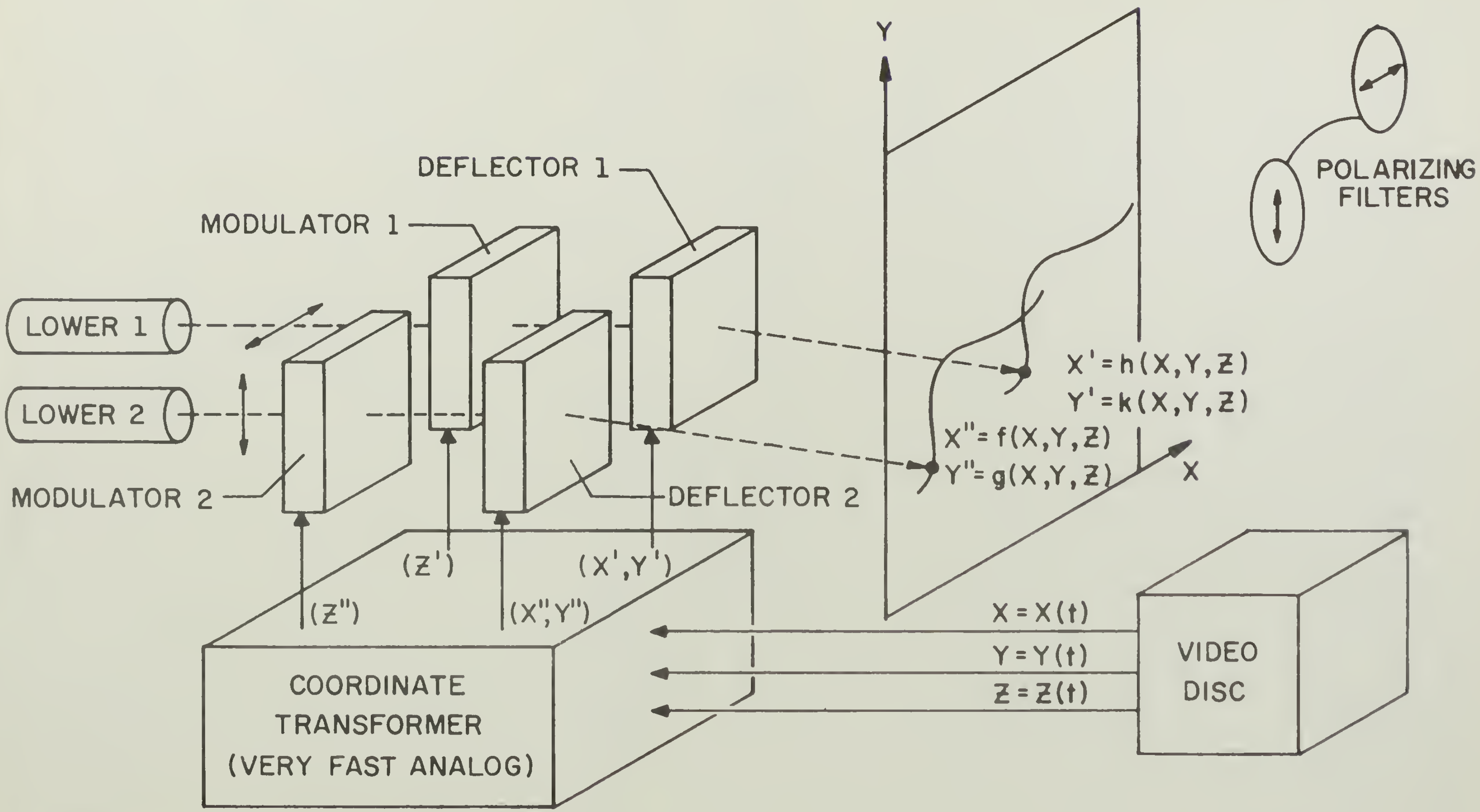


Figure 18. Principle of STEREOMATRIX

7.0 Photographs of the Equipment Discussed in Sections 3.0 through 6.0

Figure 19. The Phastor (Front view)

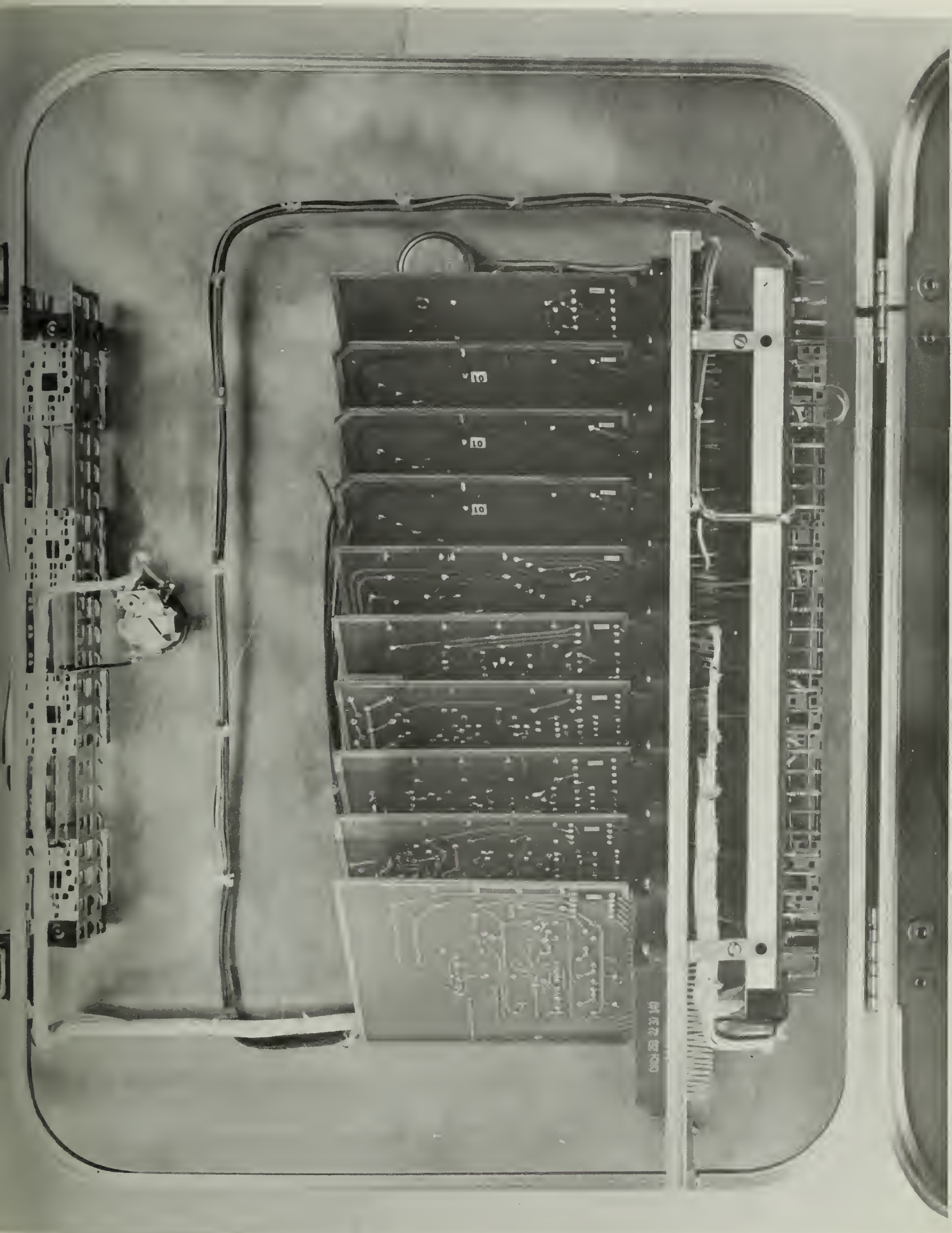


Figure 20. The Phastor (Chassis)

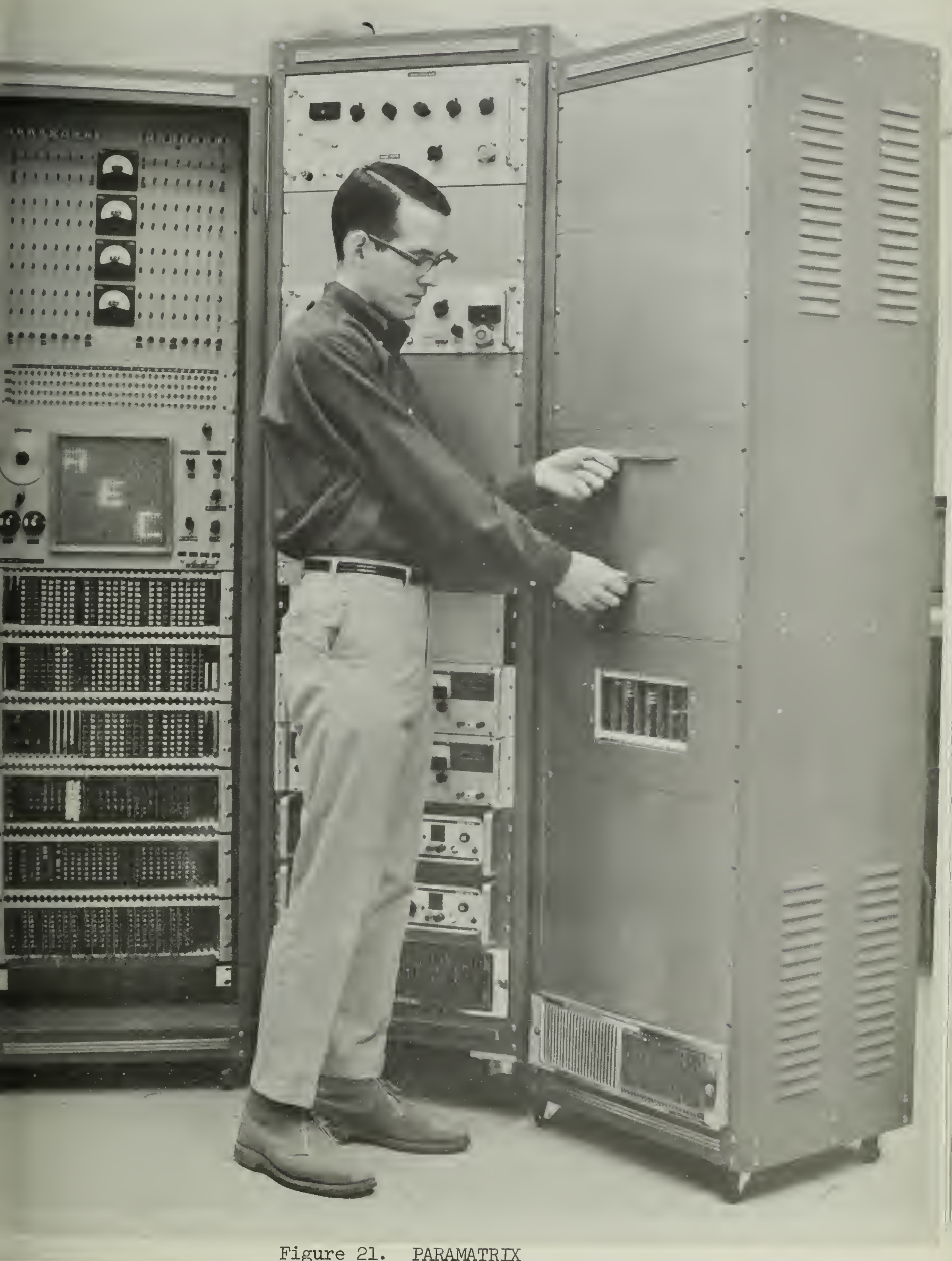


Figure 21. PARAMATRIX

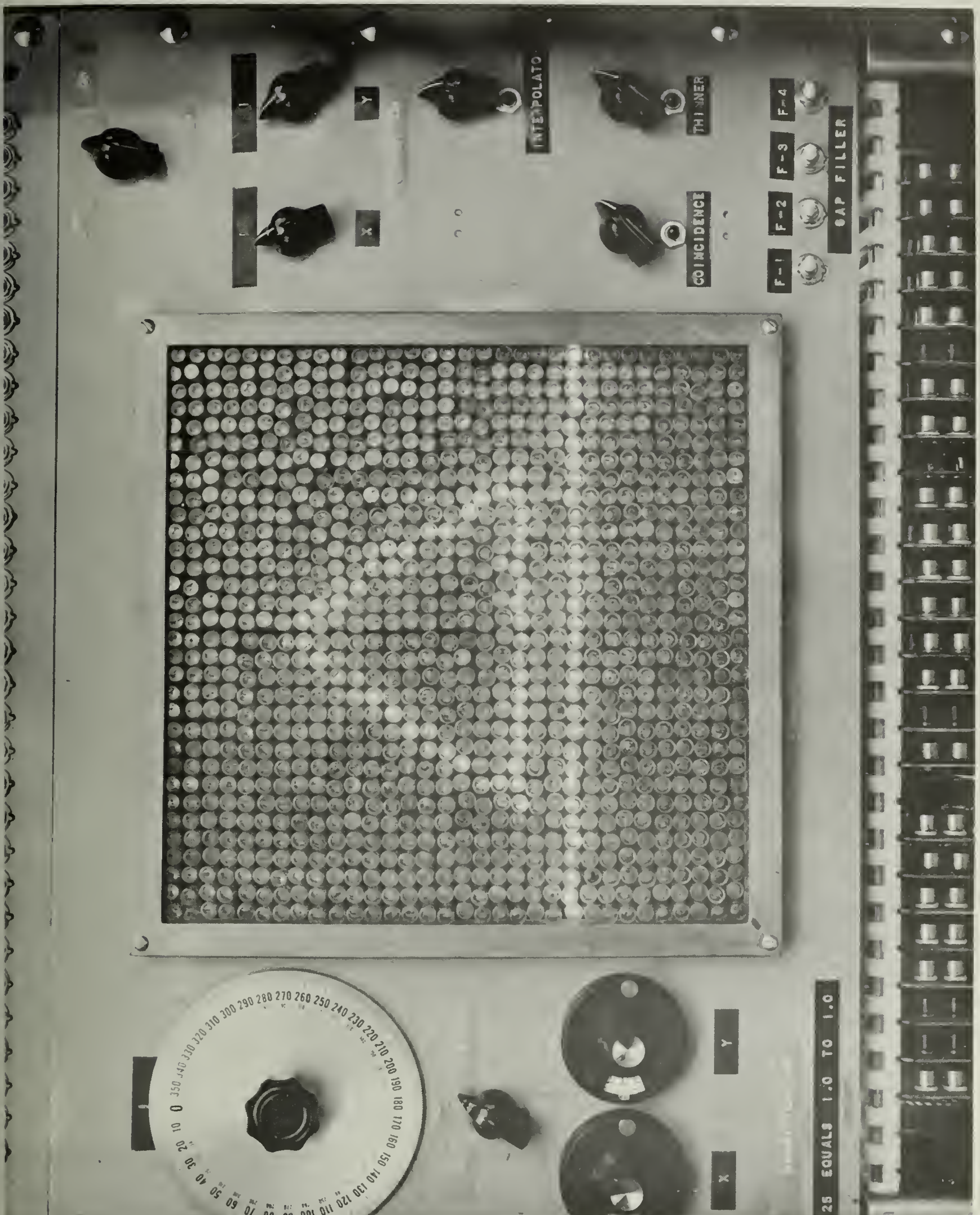


Figure 22. Close-up of PARAMATRIX Display

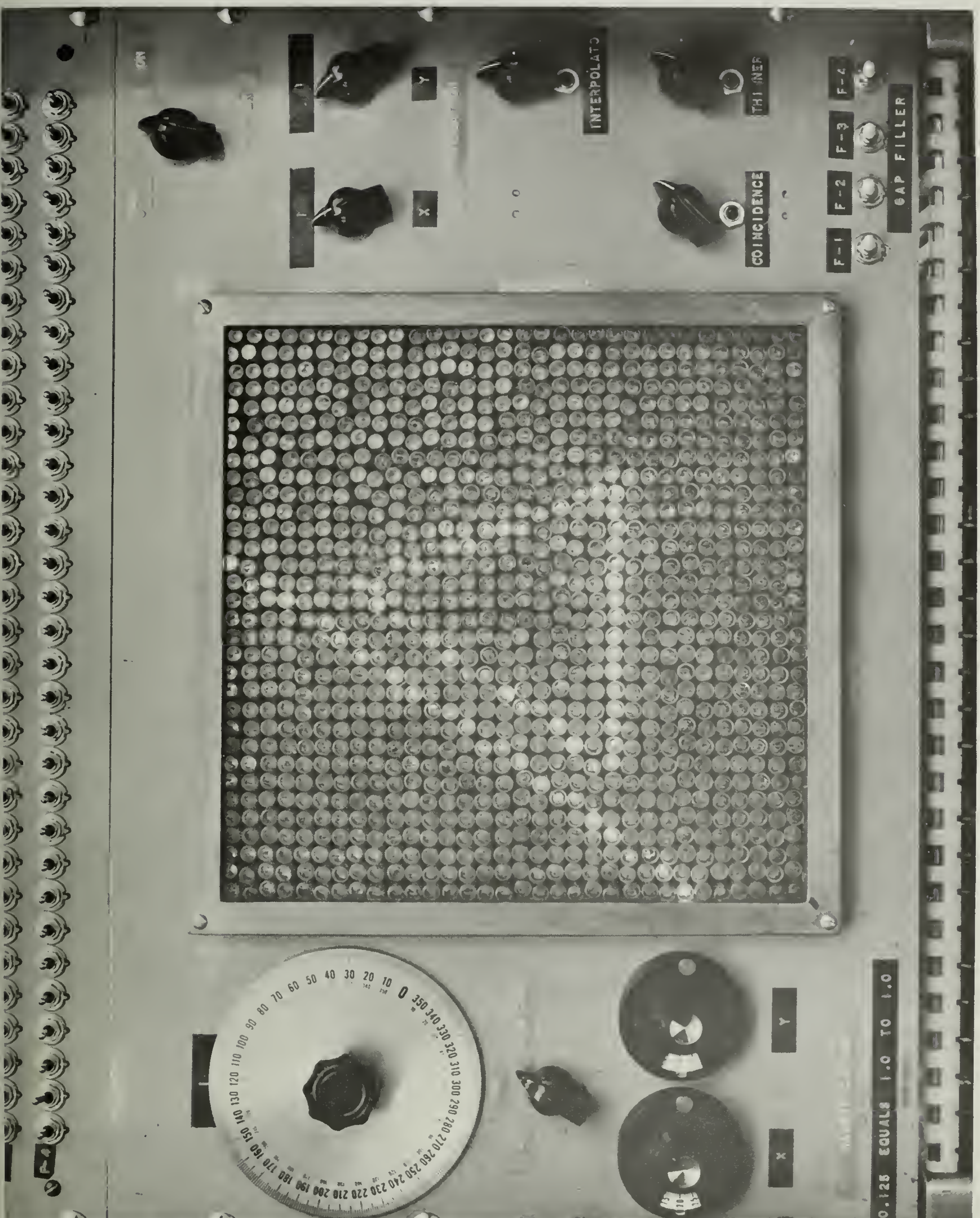


Figure 23. Close-up of PARAMATRIX Display (Showing rotation)

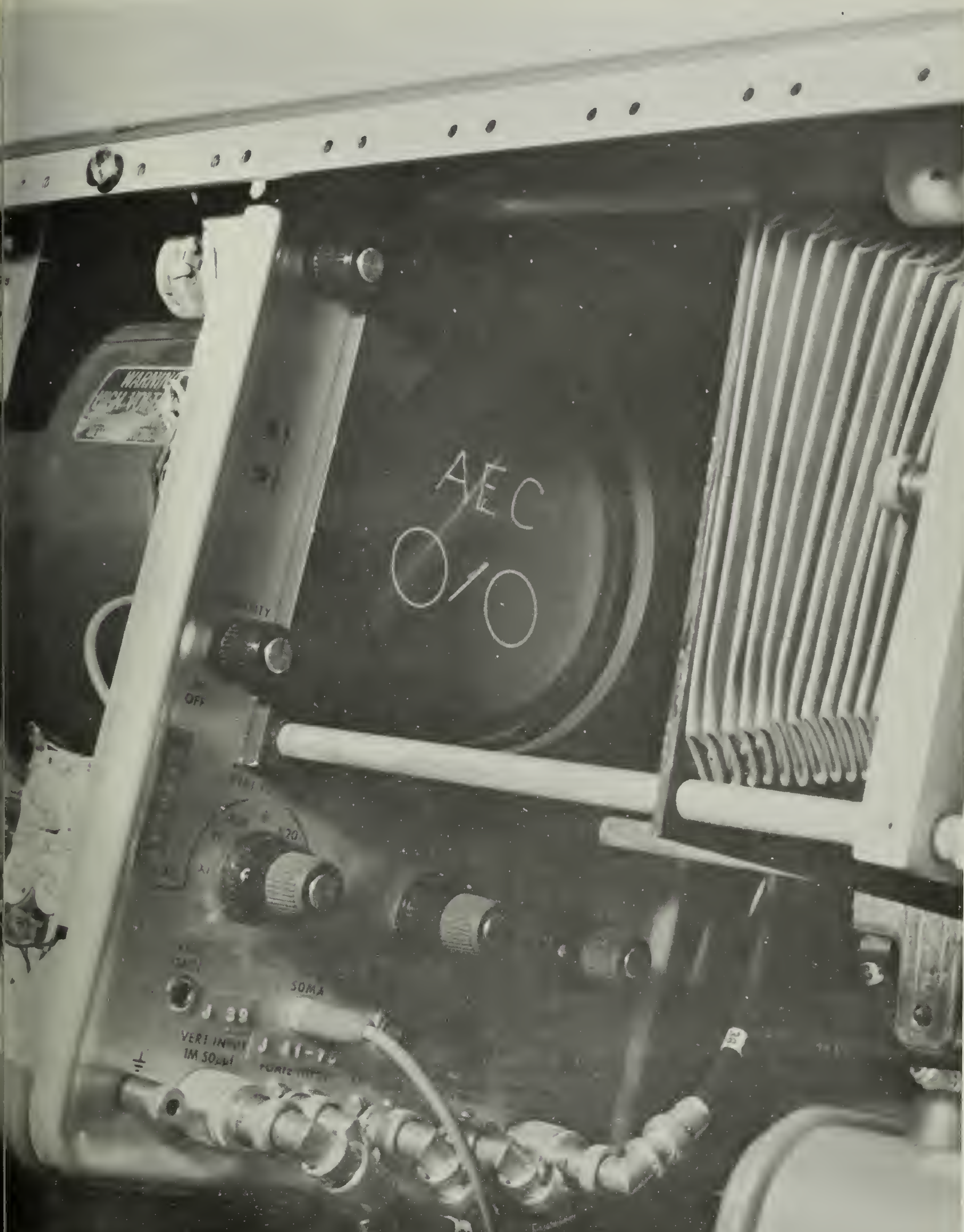


Figure 25. [illegible] Storage Tube (Close-up)

Figure 26. Tricolor Cartograph System

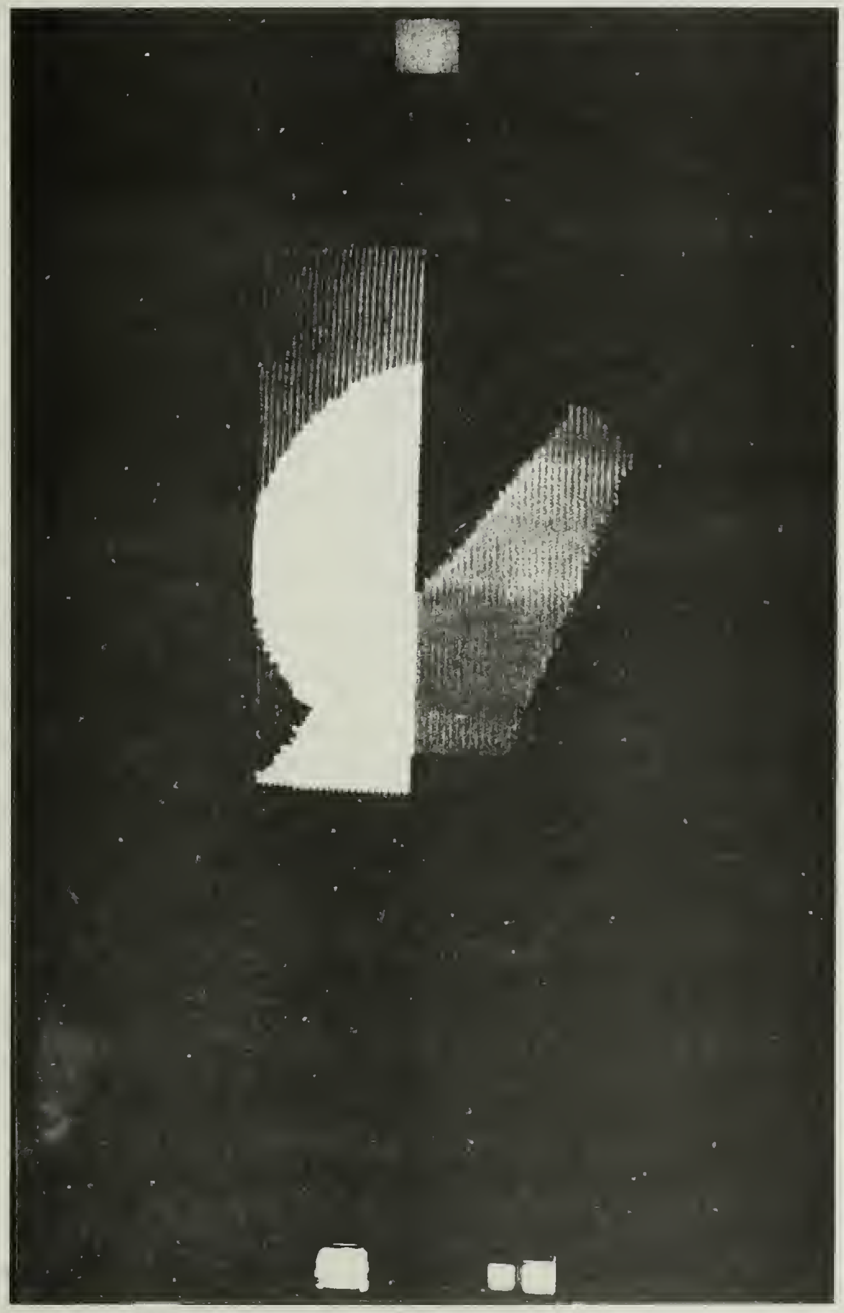


Figure 27. Tricolor Cartograph Display

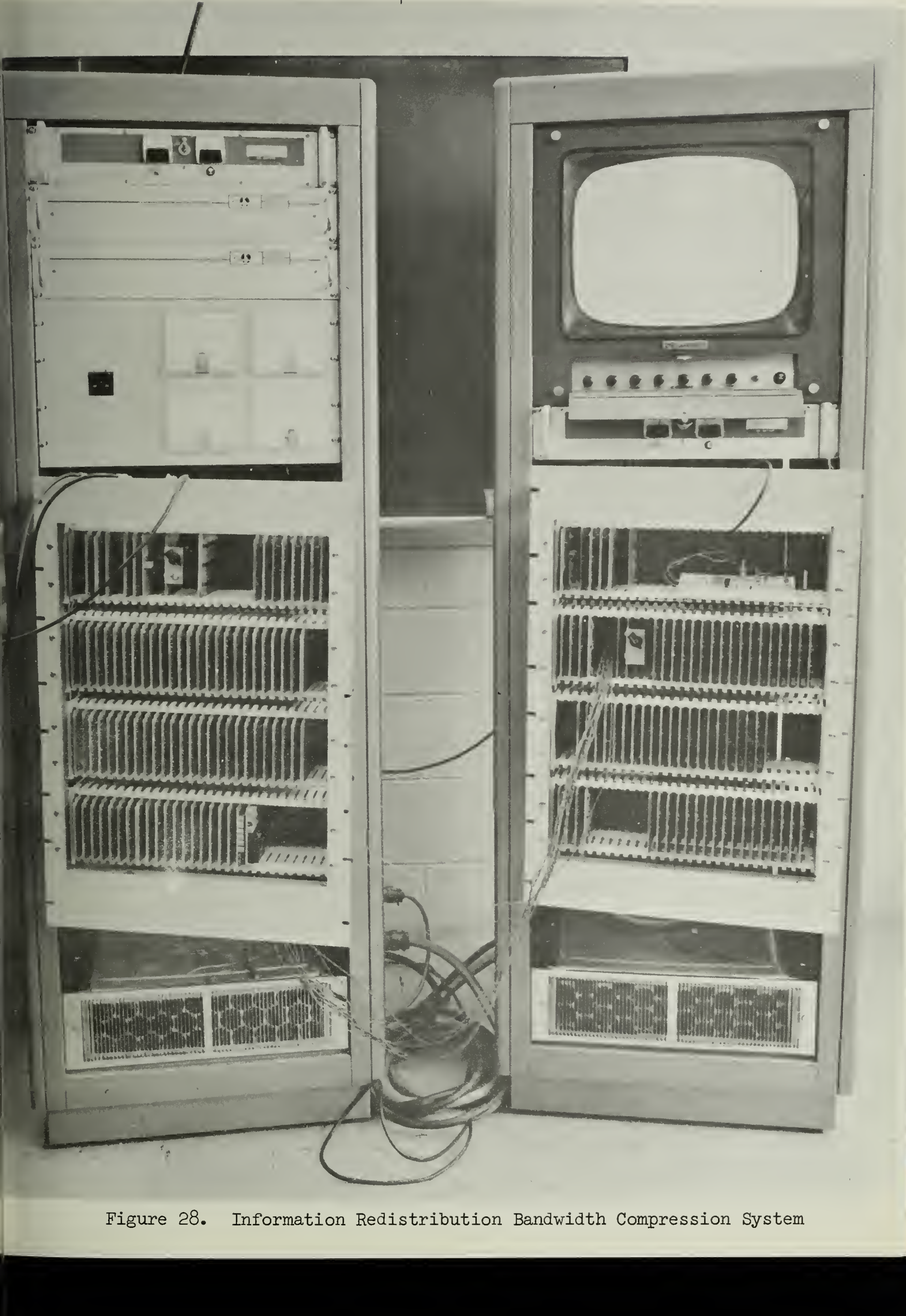


Figure 28. Information Redistribution Bandwidth Compression System

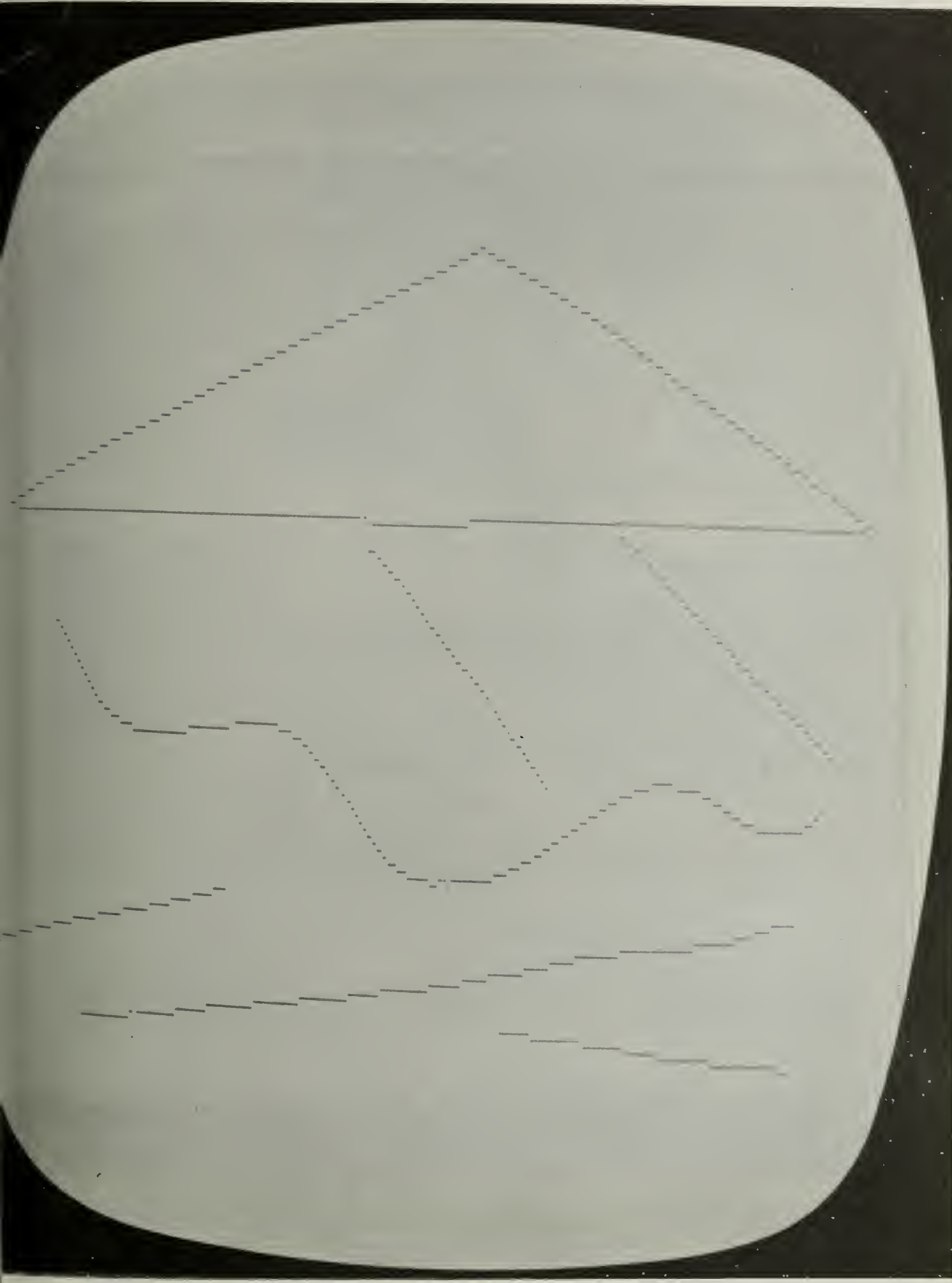


Figure 30. VISTA (Variable Interlace System for Television Applications)

Figure 31. Stochastic Processor Model

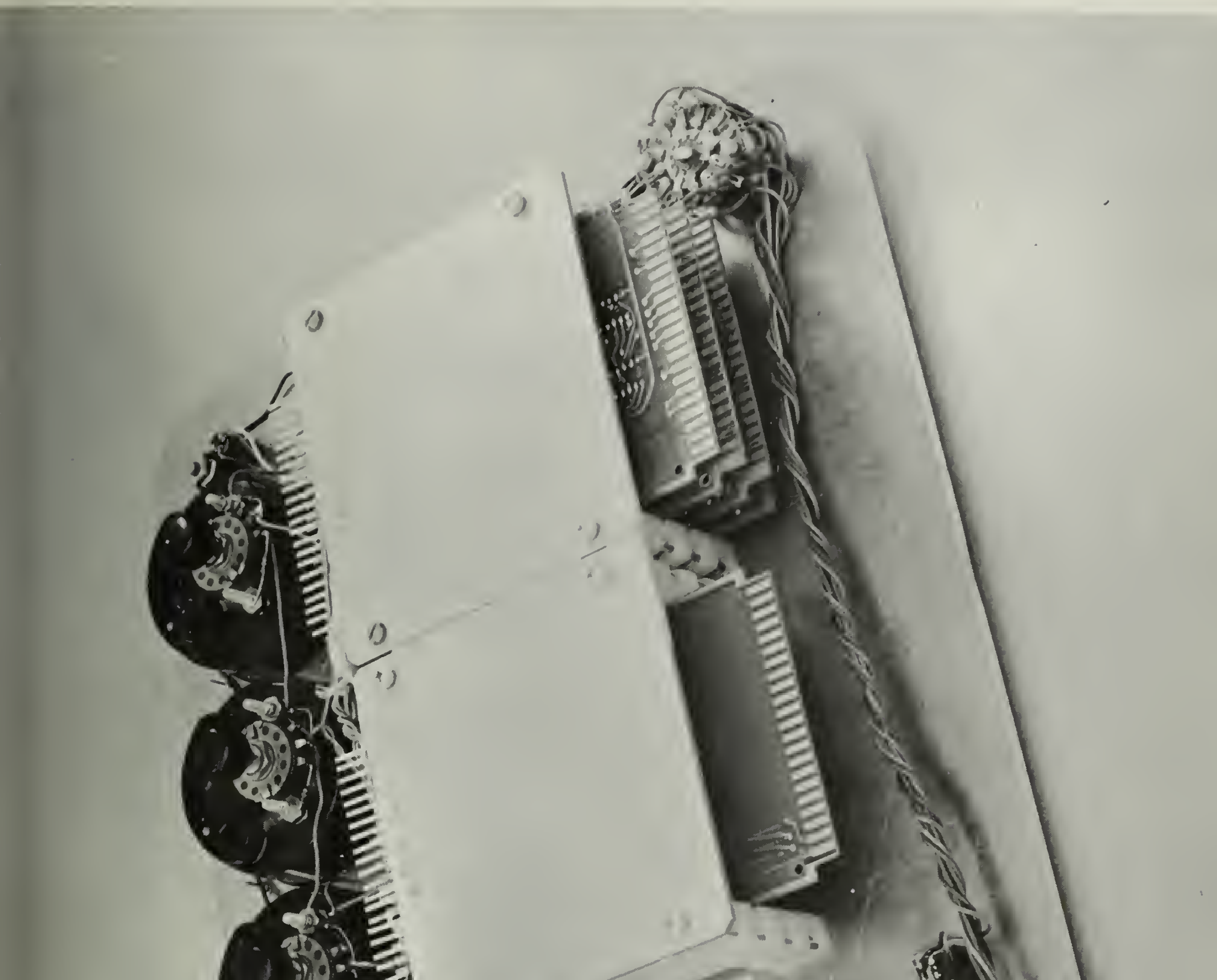
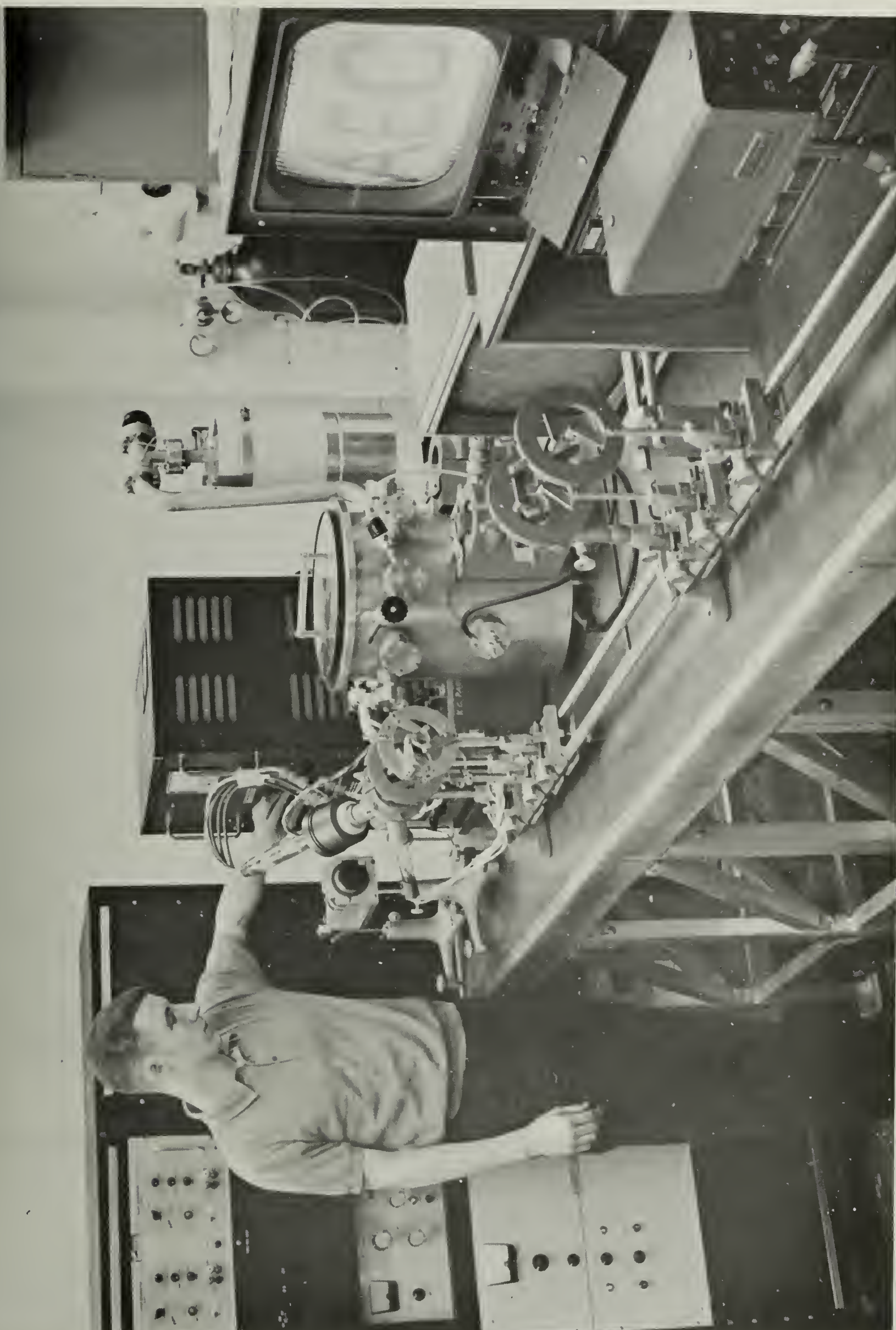
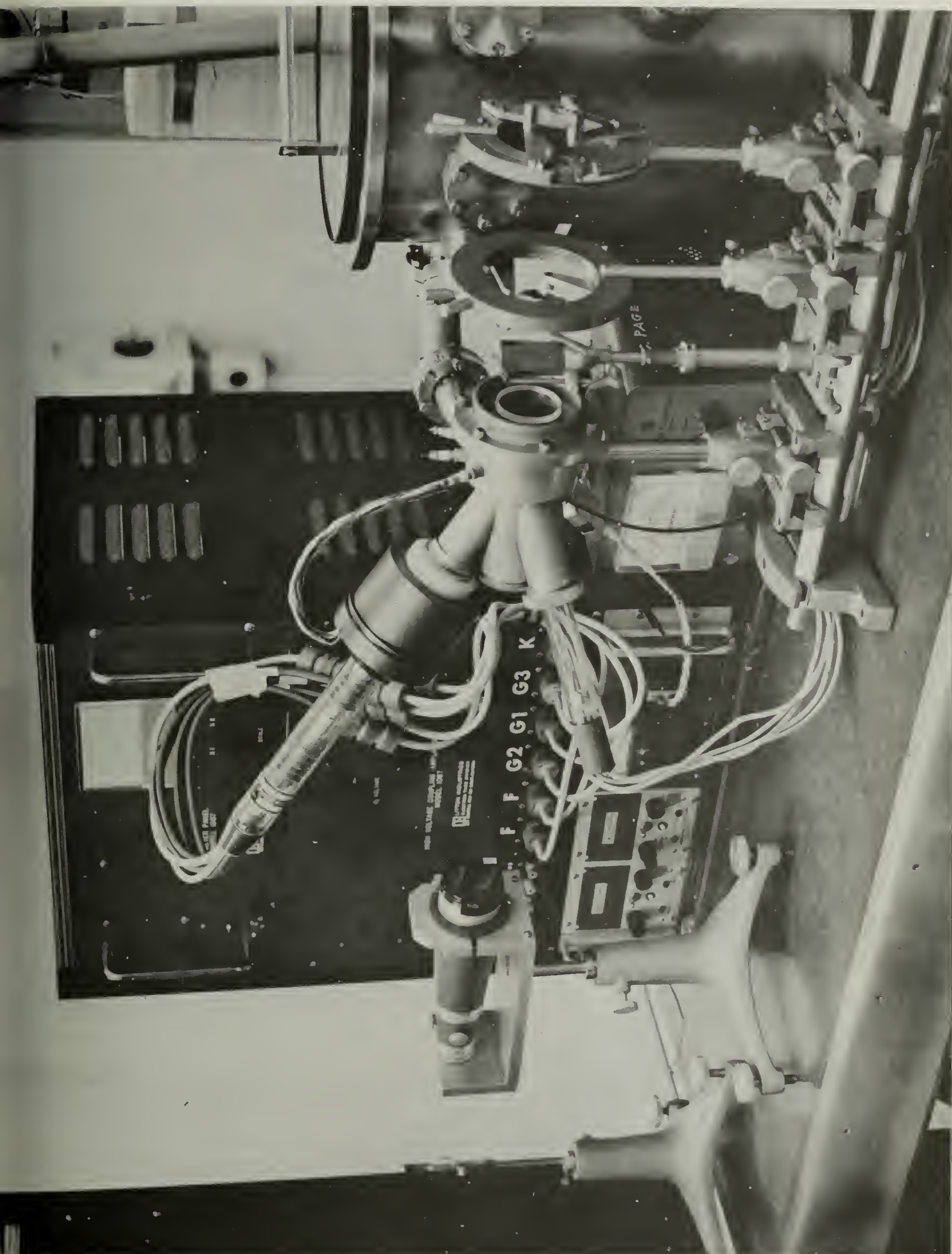


Figure 32. Stochastic Processor Model (Inside)

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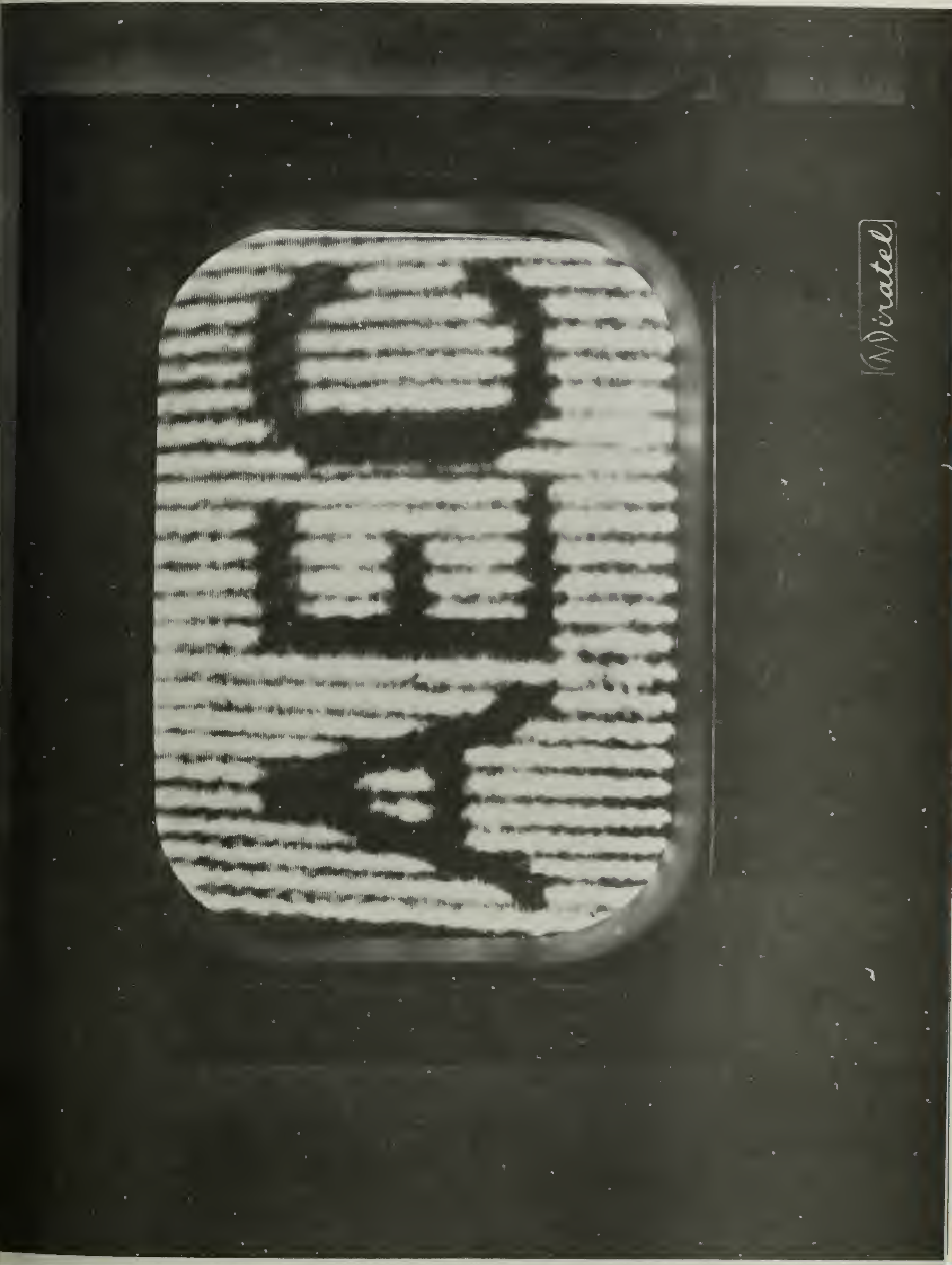

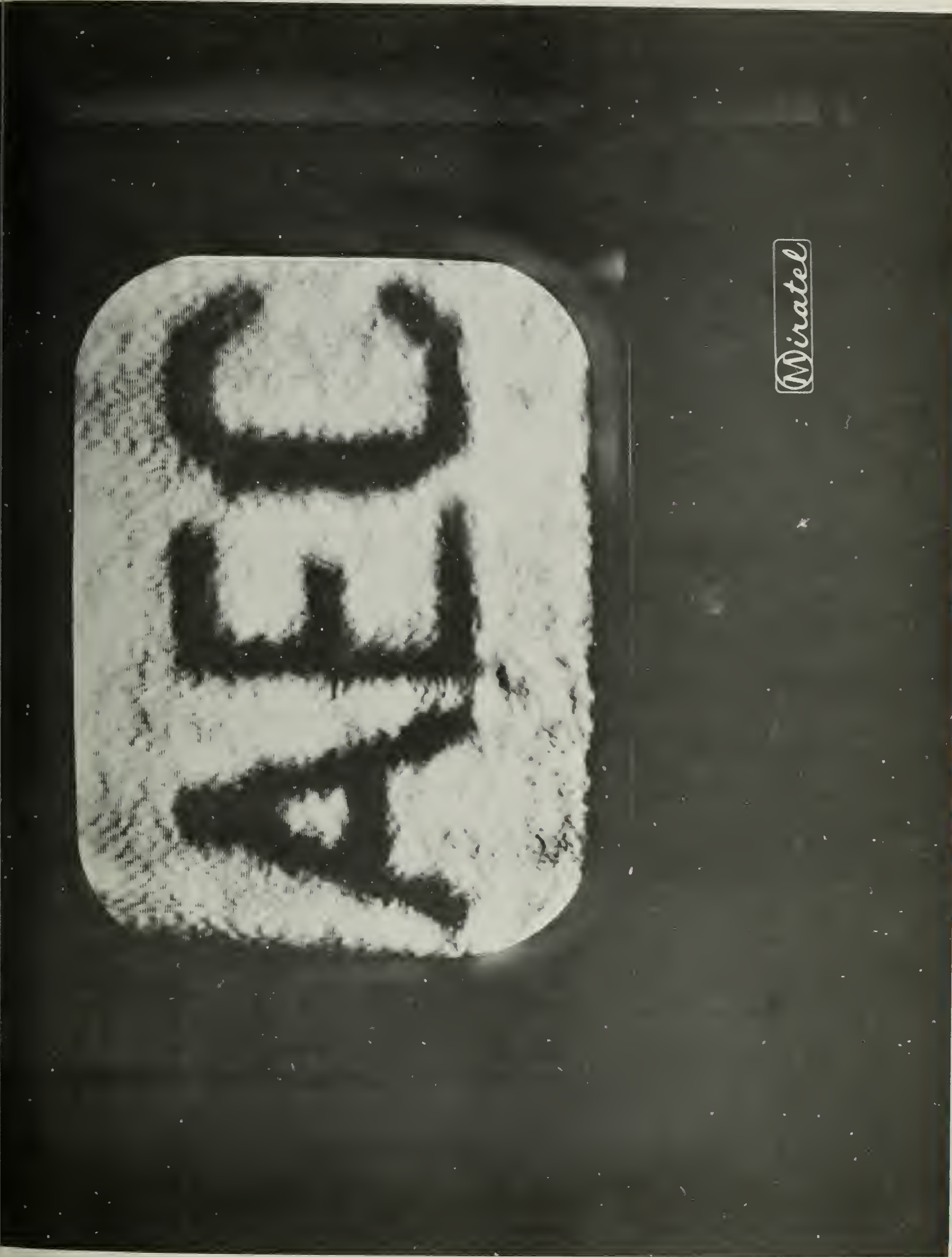
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Miratel

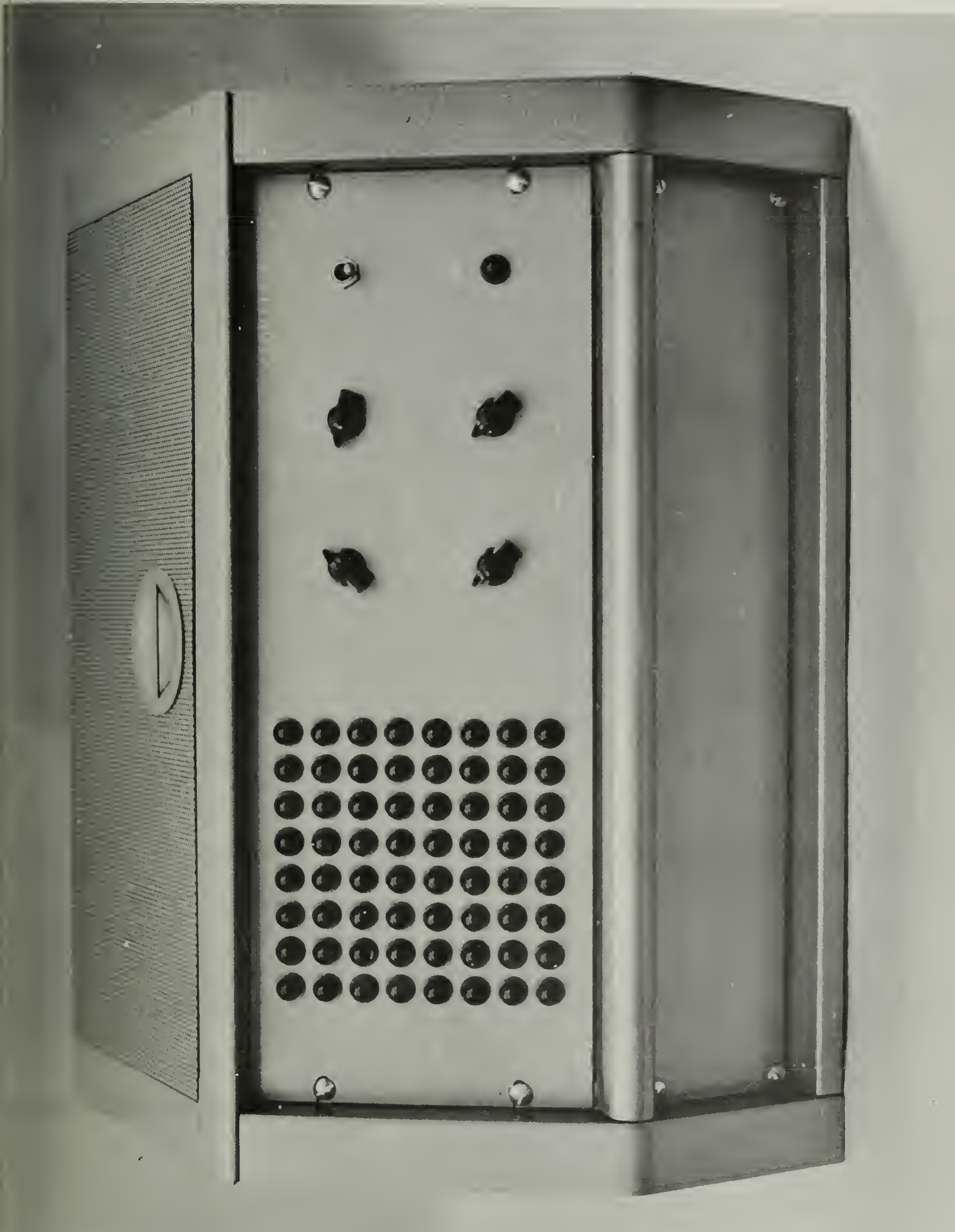
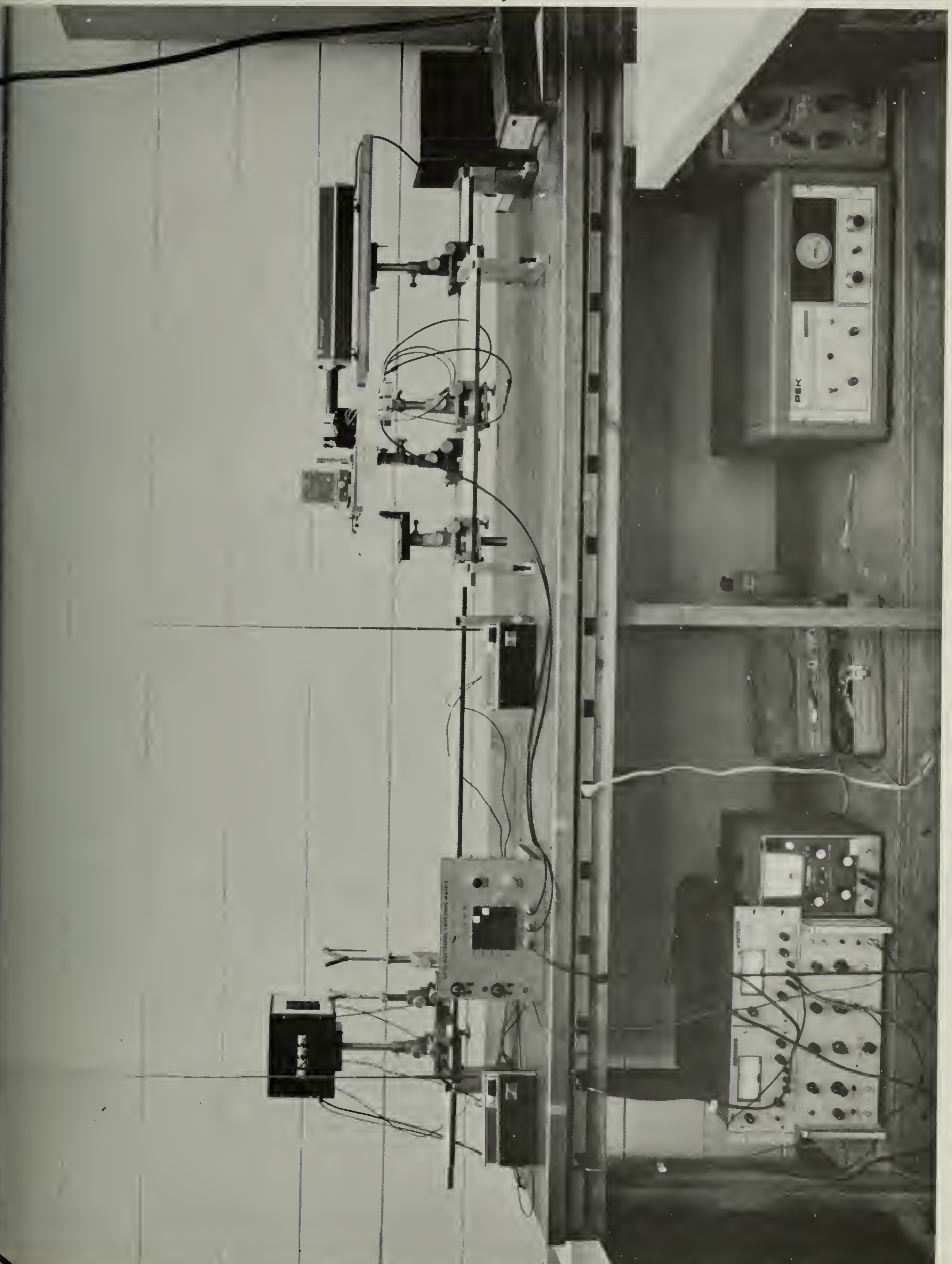


Figure 37. GEOMATRIX



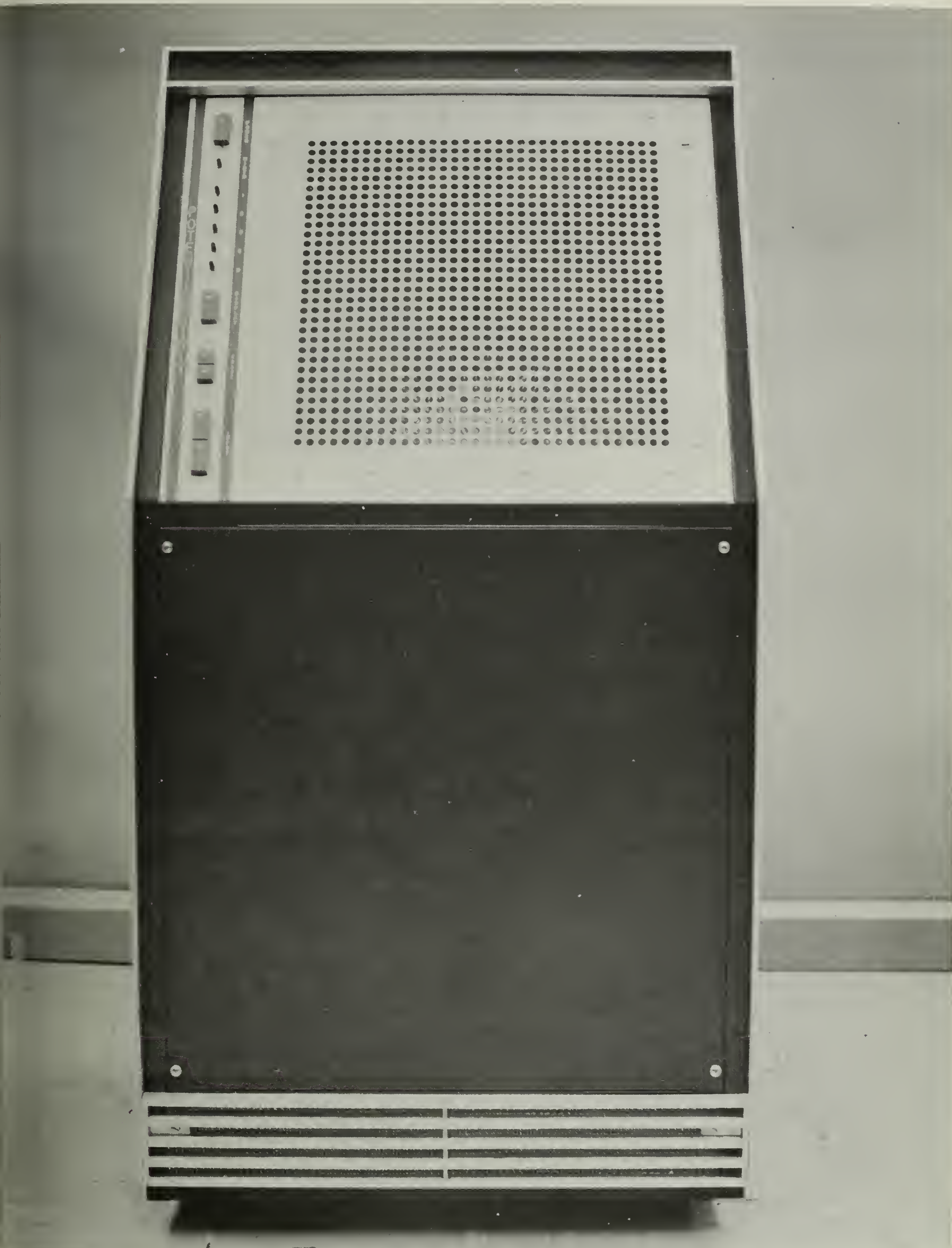


Figure 39. POTENTIOMATRIX

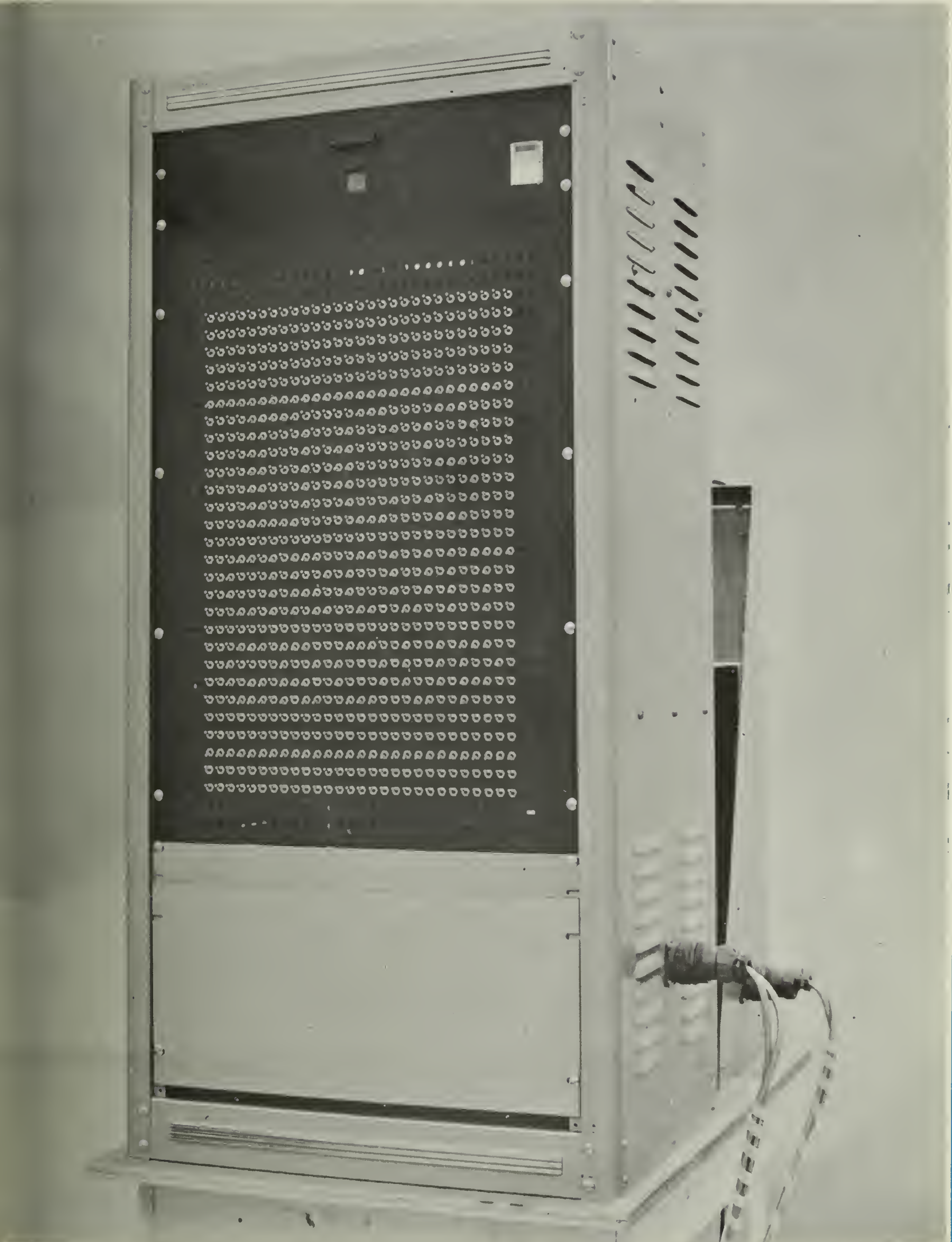
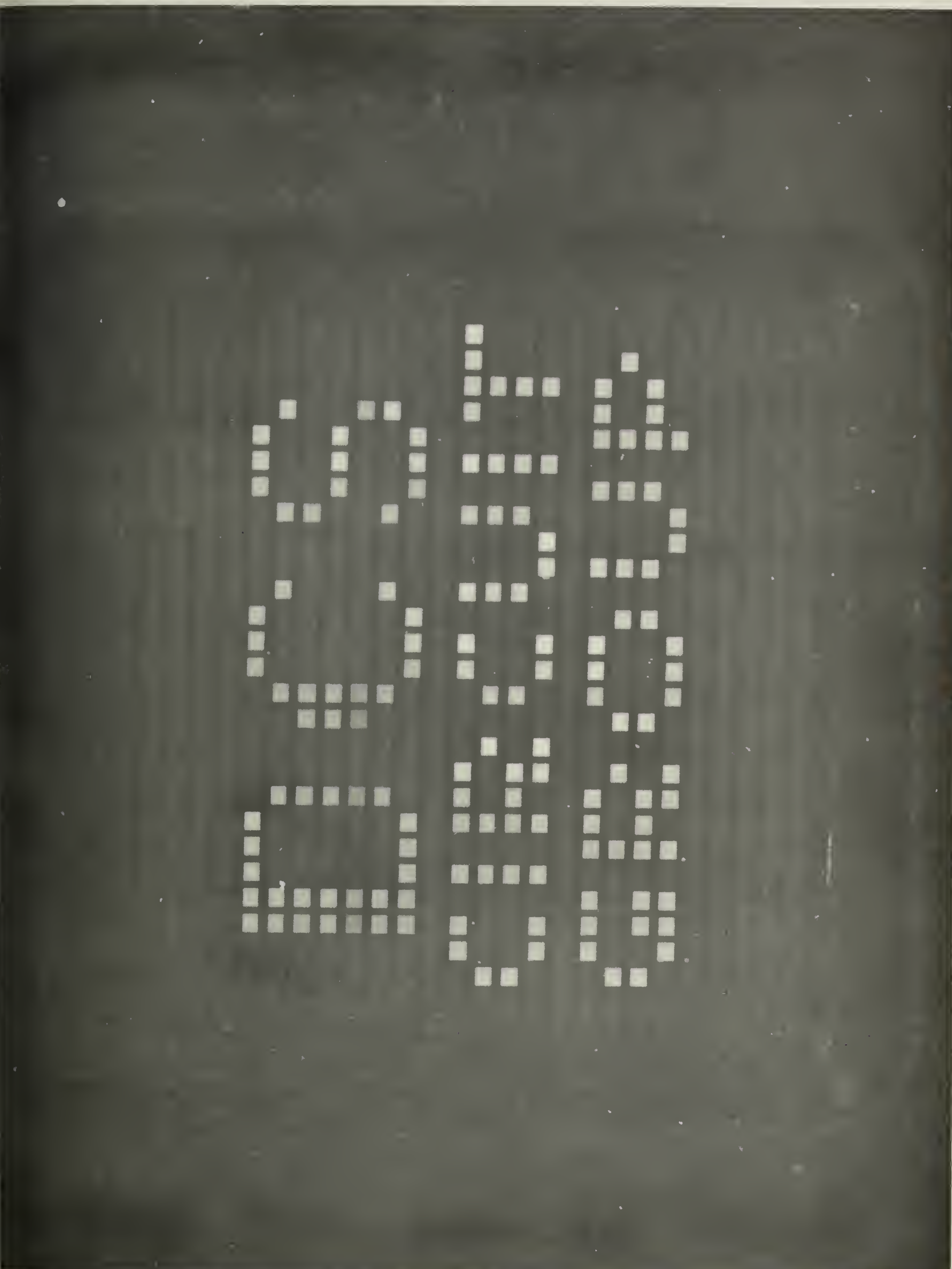


Figure 40. Electrolumenescent Panel



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193	An Application of Intercoupled-Transmission-Line Amplifiers	C. Afuso	11/1/65
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